What do optical observations tell us about Gamma Ray Bursts Physics?

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in collaboration with
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Perspectives on the Extragalactic Frontier: from Astrophysics to Fundamental Physics
International Centre for Theoretical Physics, Trieste
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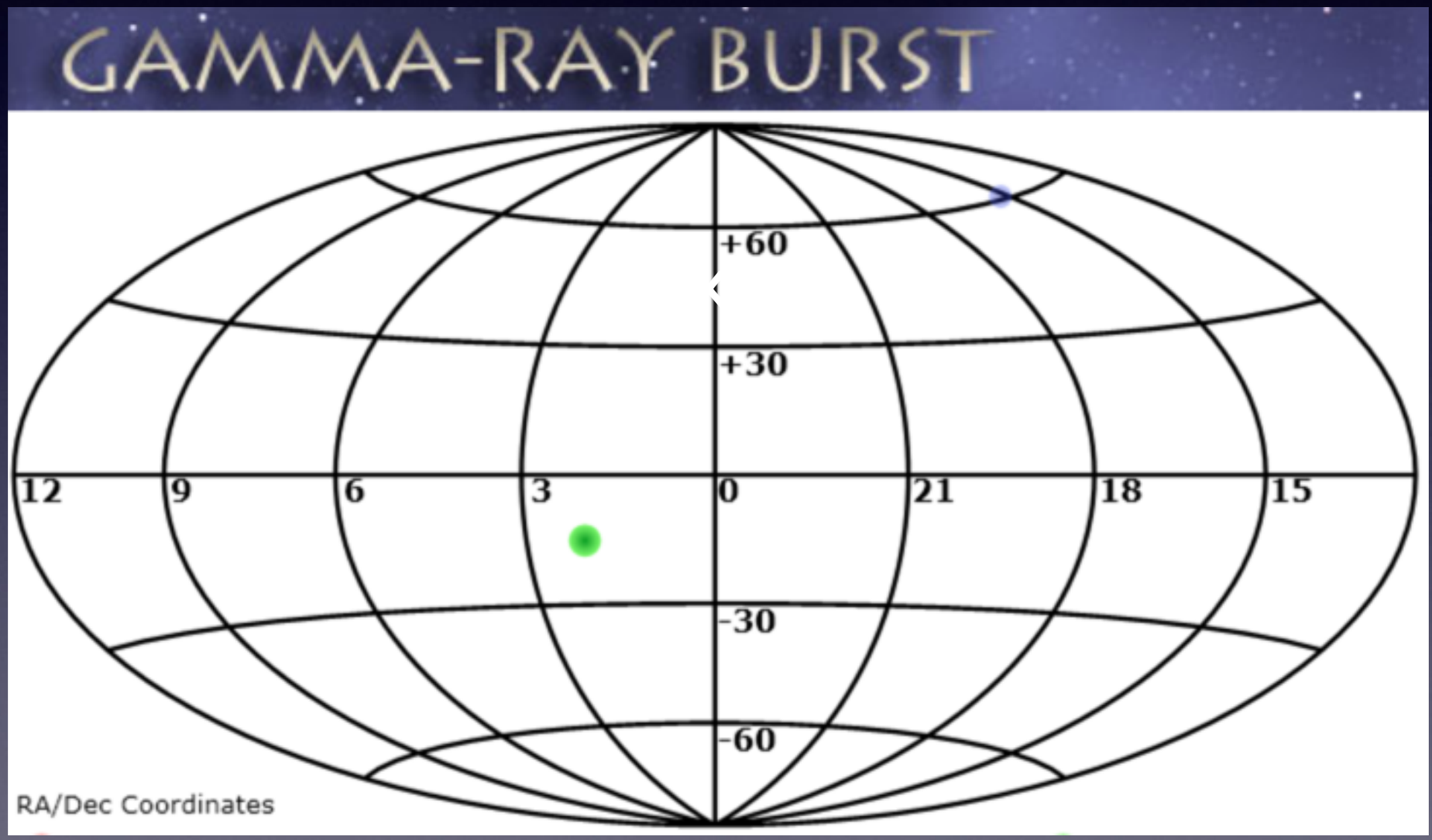
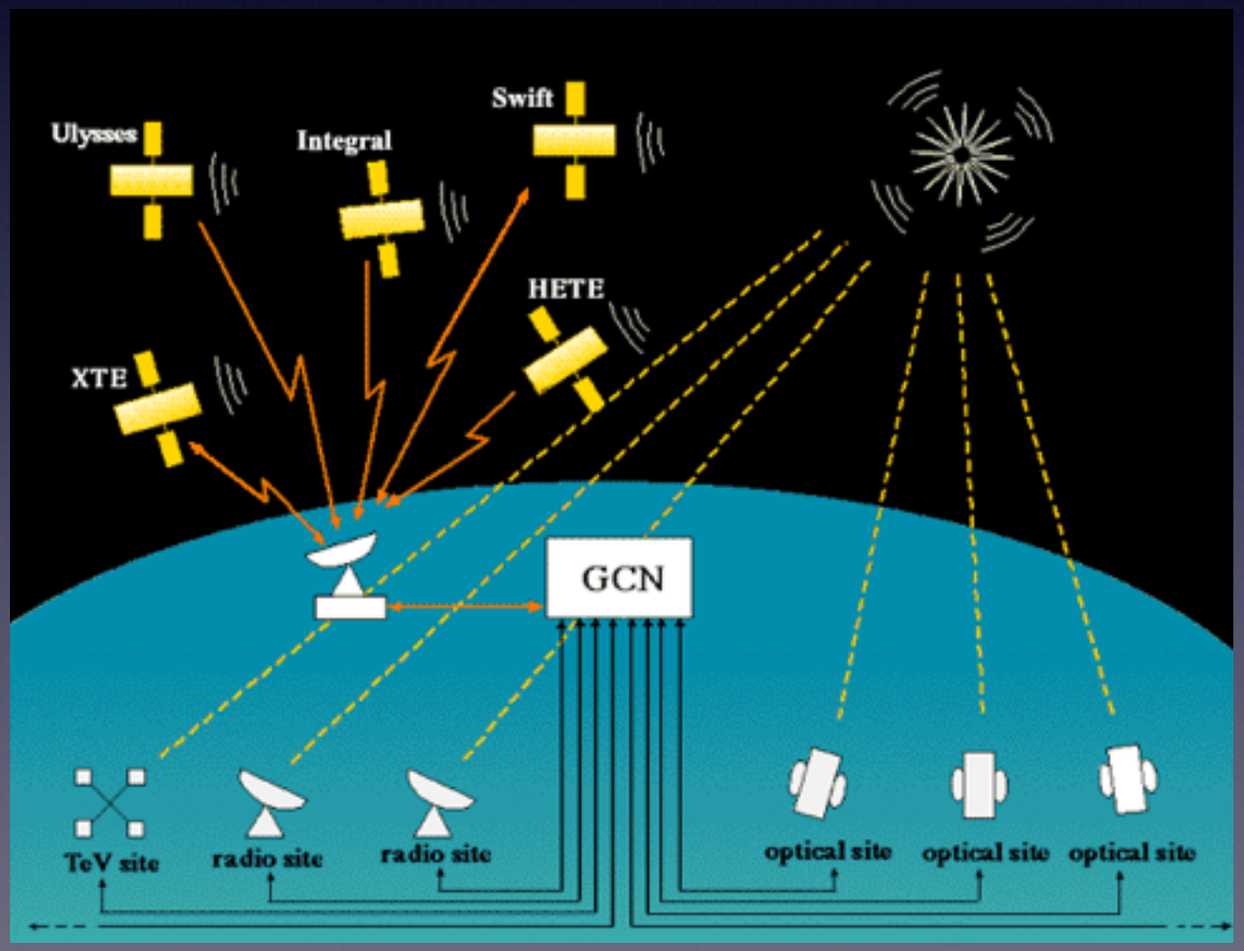
GRB afterglows

GRB goes off...



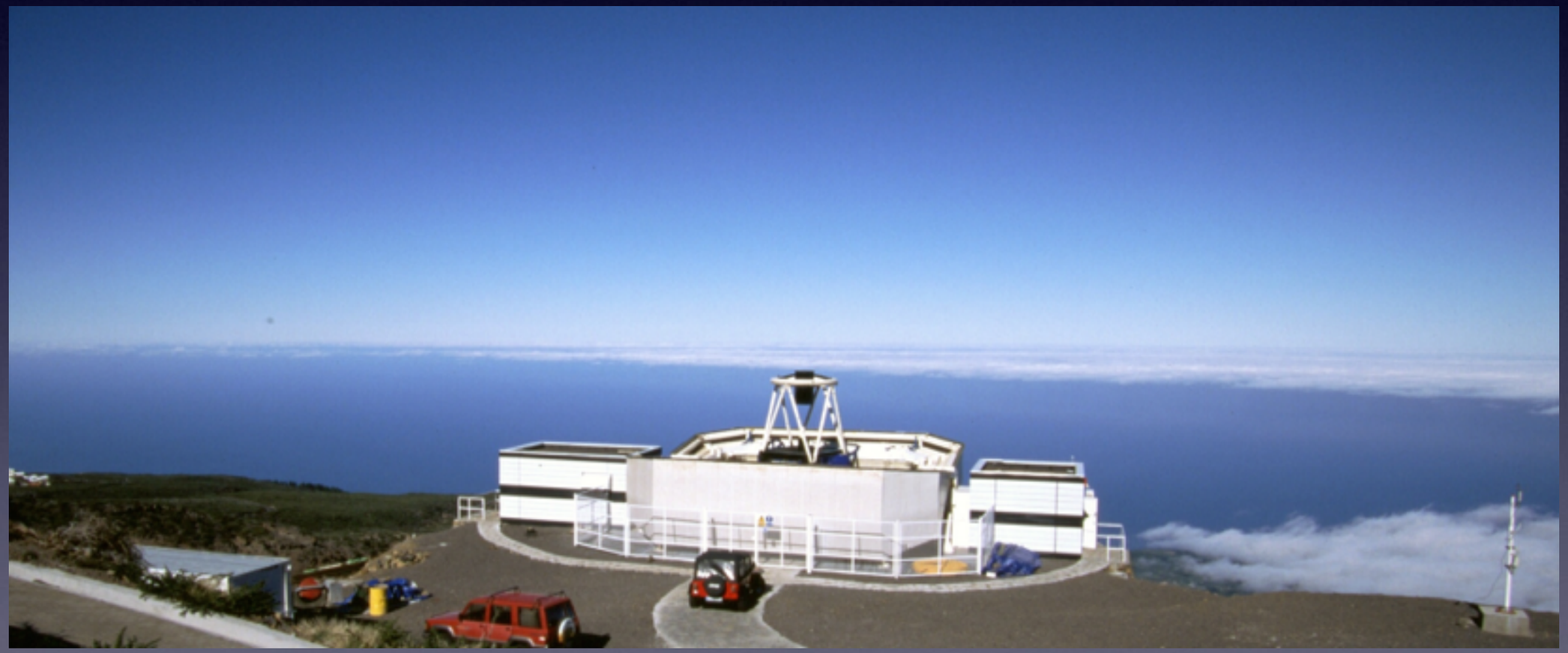
GRB alerts via Gamma Ray Burst Coordinates Network (GCN)

in real-time: location - error-box etc.



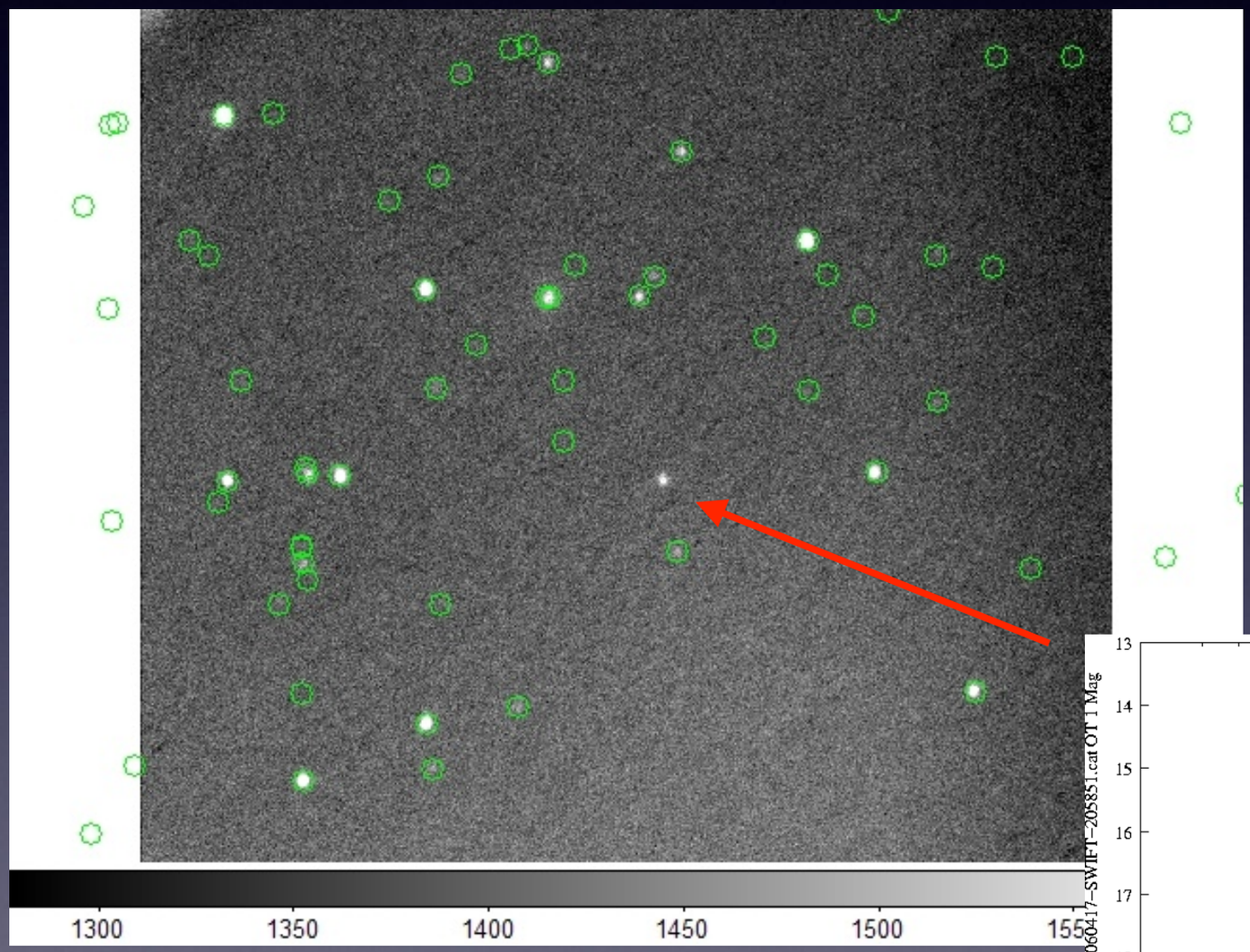
TITLE: GCN/SWIFT NOTICE
NOTICE_DATE: Fri 16 May 14 20:31:17 UT
NOTICE_TYPE: Swift-BAT GRB Position
TRIGGER_NUM: 599188, Seg_Num: 0
GRB_RA: 252.988d {+16h 51m 57s} (J2000),
253.108d {+16h 52m 26s} (current),
252.571d {+16h 50m 17s} (1950)
GRB_DEC: +39.915d {+39d 54' 53"} (J2000),
+39.891d {+39d 53' 29"} (current),
+39.997d {+39d 59' 50"} (1950)
GRB_ERROR: 3.00 [arcmin radius, statistical only]
GRB_INTEN: 608 [cnts] Image_Peak=59 [image_cnts]
TRIGGER_DUR: 0.128 [sec]
TRIGGER_INDEX: 122 E_range: 25-100 keV
BKG_INTEN: 22079 [cnts]
BKG_TIME: 73843.98 SOD {20:30:43.98} UT
BKG_DUR: 8 [sec]
GRB_DATE: 16793 TJD; 136 DOY; 14/05/16
GRB_TIME: 73854.79 SOD {20:30:54.79} UT
GRB_PHI: 40.67 [deg]
GRB_THETA: 22.69 [deg]
SOLN_STATUS: 0x83
RATE_SIGNIF: 13.41 [sigma]
IMAGE_SIGNIF: 6.73 [sigma]
MERIT_PARAMS: +1 +0 +0 -3 +2 -3 +0 +0 +47 +0
SUN_POSTN: 53.57d {+03h 34m 16s} +19.23d {+19d 13' 39"}
SUN_DIST: 118.13 [deg] Sun_angle= 10.7 [hr] (West of Sun)
MOON_POSTN: 262.65d {+17h 30m 35s} -19.06d {-19d 03' 19"}
MOON_DIST: 59.62 [deg]
MOON_ILLUM: 94 [%]
GAL_COORDS: 63.76, 39.24 [deg] galactic lon,lat of the burst (or transient)
ECL_COORDS: 241.75, 61.70 [deg] ecliptic lon,lat of the burst (or transient)
COMMENTS: SWIFT-BAT GRB Coordinates.
COMMENTS: This is a rate trigger.
COMMENTS: A point_source was found.
COMMENTS: This does not match any source in the on-board catalog.
COMMENTS: This does not match any source in the ground catalog.
COMMENTS: This is a GRB.
COMMENTS: Since the IMAGE_SIGNIF is less than 7 sigma, this is a questionable detection.
COMMENTS: This trigger occurred at longitude,latitude = 338.30,20.57 [deg].

Liverpool Telescope, La Palma, Canary Islands



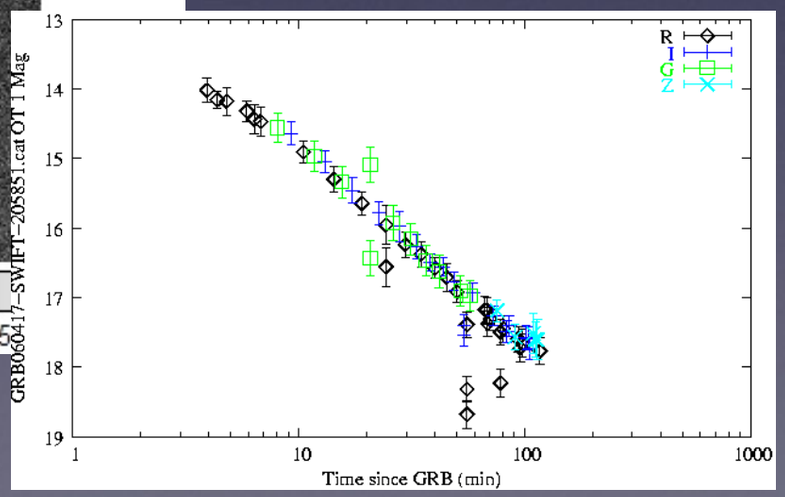
2-m Liverpool Telescope + LCOGTN

optical afterglow detection



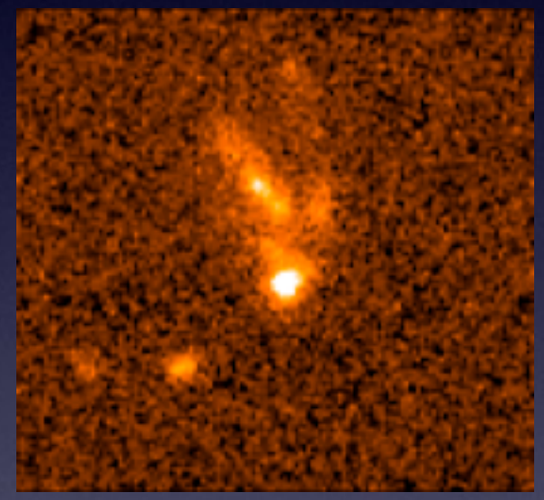
LT-TRAP (Liverpool Telescope Transient Rapid Analysis Pipeline)

automatic identification and light curves in real-time

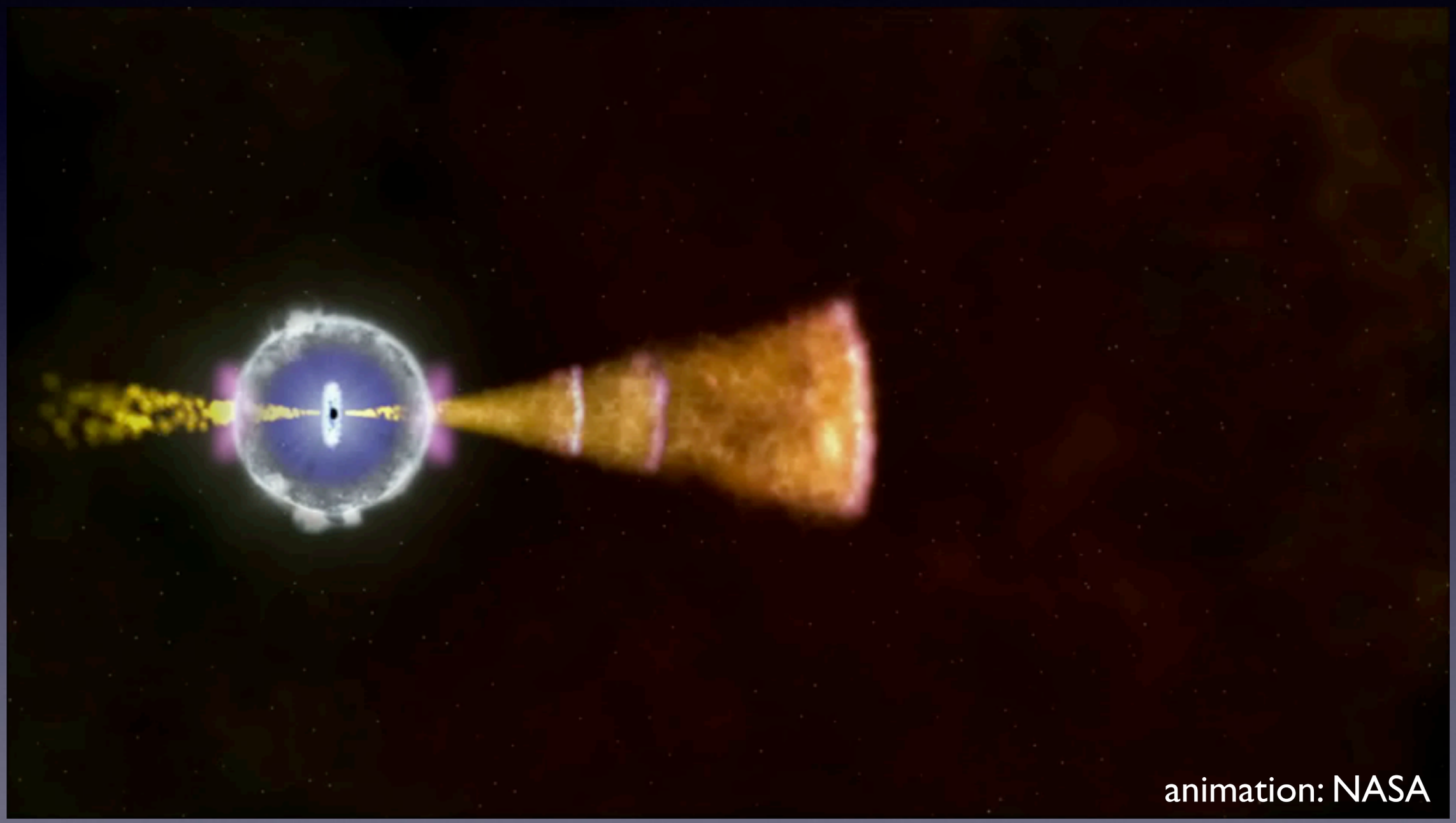


late time observations

- with larger telescopes (WHT, VLT, Gemini...)
- afterglow photometry, spectroscopy, polarimetry
- host galaxy observations



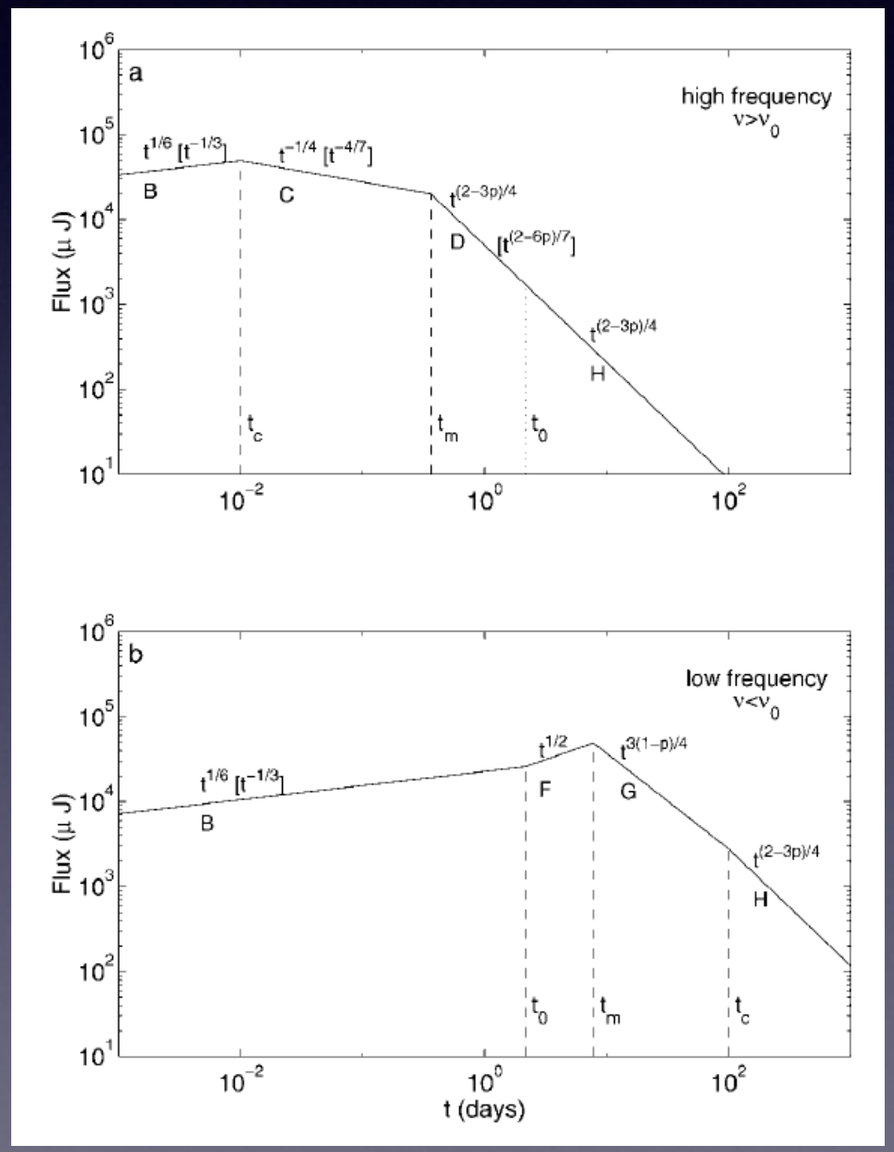
where are afterglows produced?



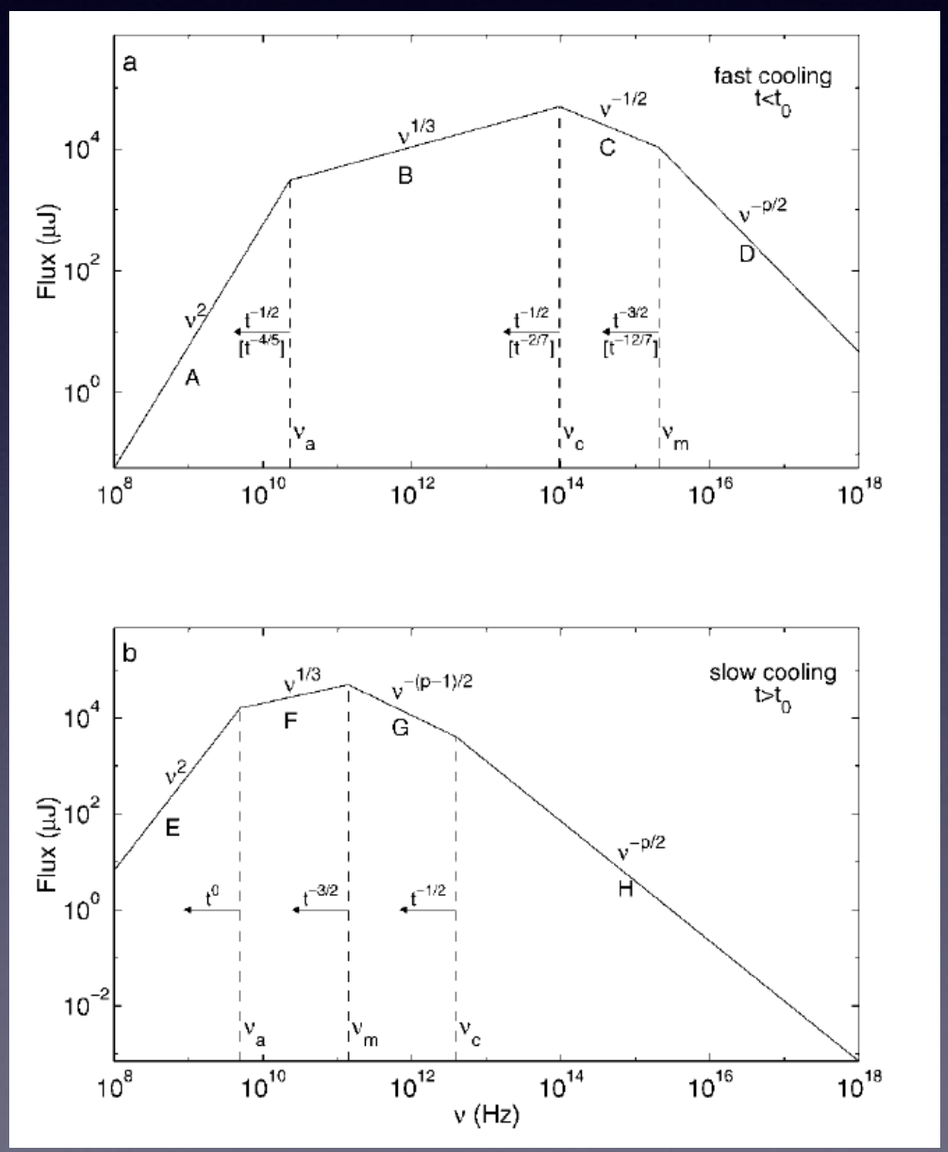
electron distribution: $N(\gamma_e)d\gamma_e \propto \gamma_e^{-p}d\gamma_e, \gamma_e \geq \gamma_m$

Flux: $F_\nu(t) \propto t^{-\alpha} \nu^{-\beta}$

afterglow light curve:



spectral energy distribution:



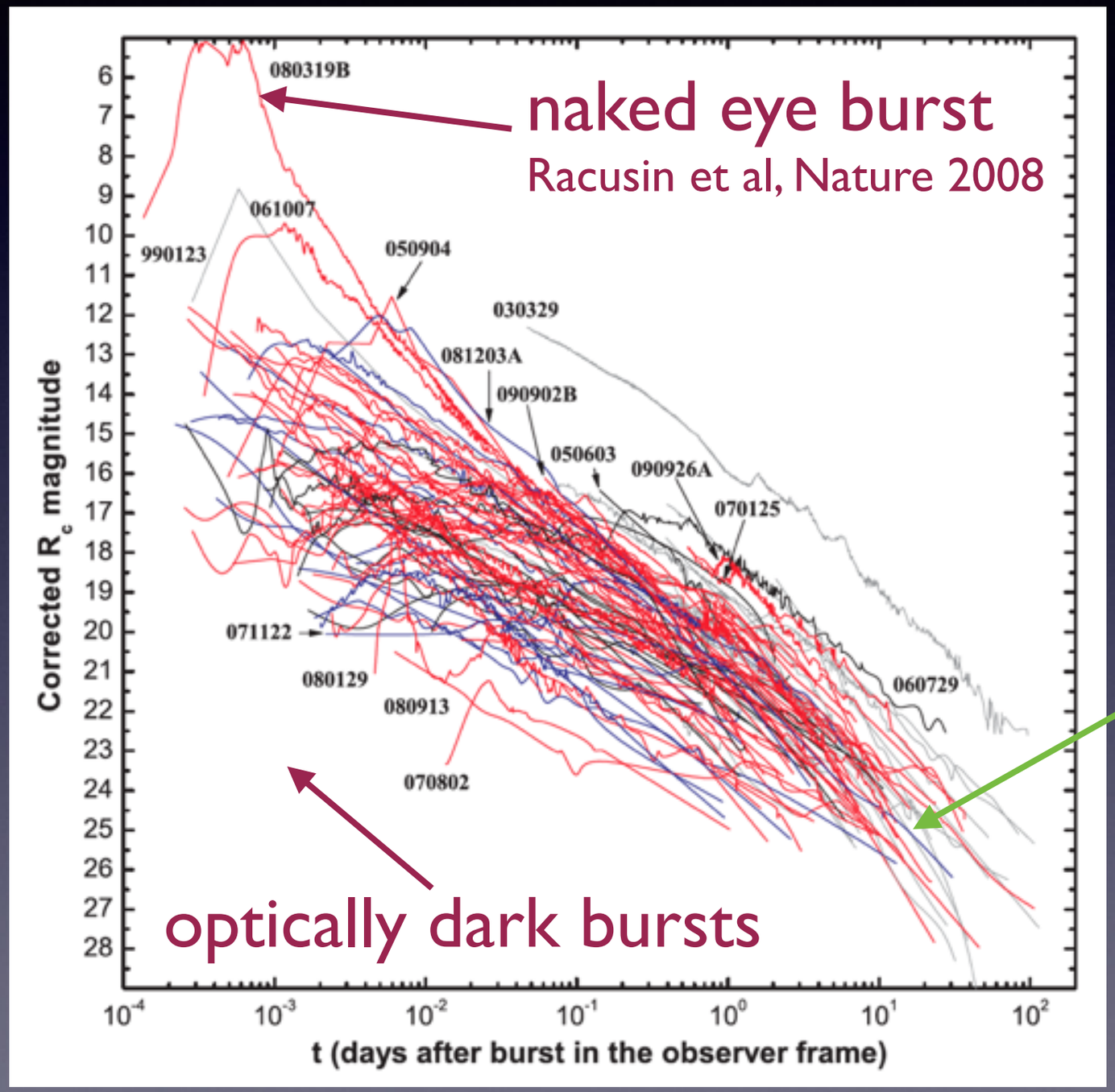
Sari et al, 1998

multi-wavelength studies

what do observations tell us?

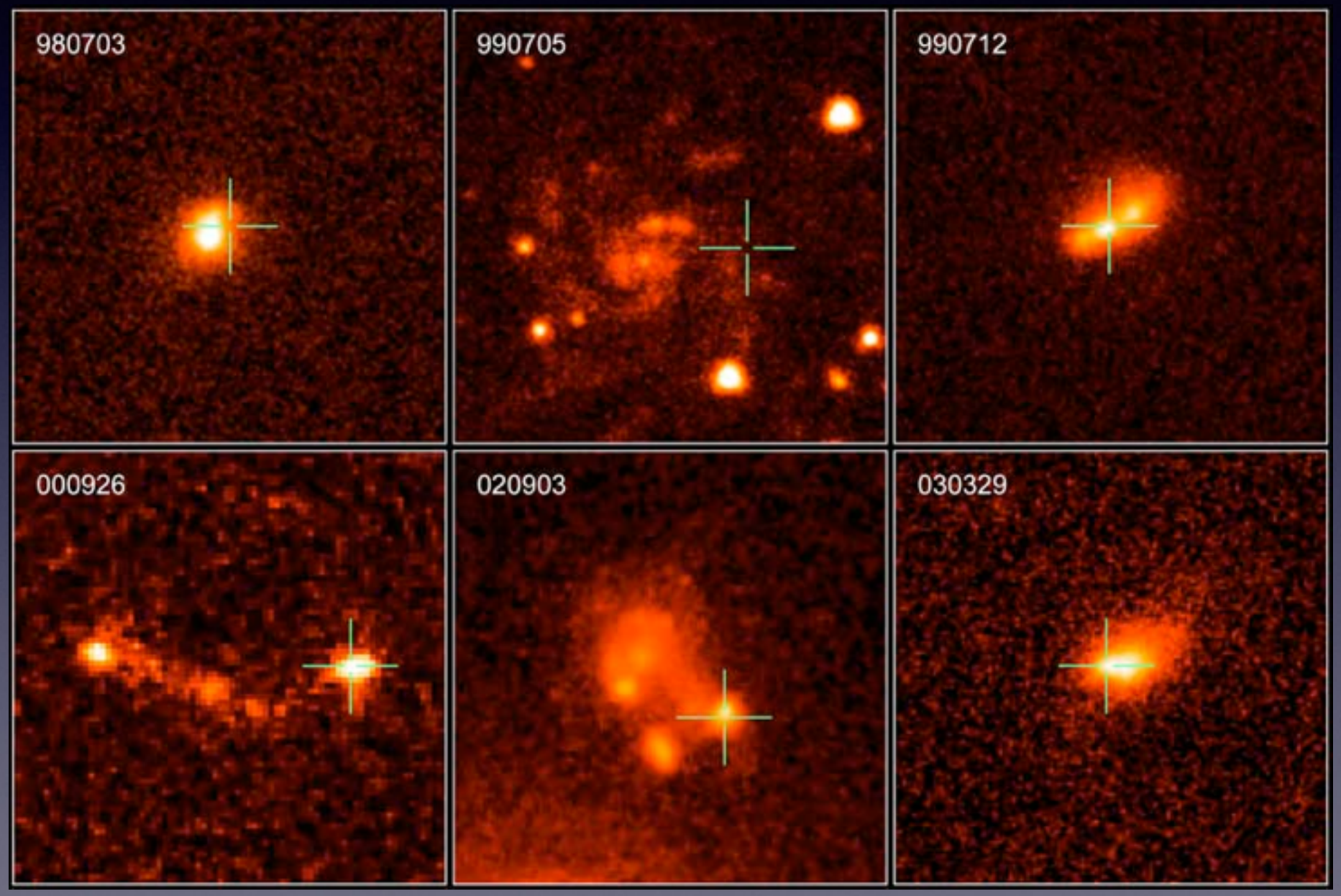
- different things in different wavelength bands and at different times
  - rapid and short wavelengths: closer
  - later and longer wavelengths: further
  - still later: host galaxy
  - complementary information

optical afterglows



Kann et al. 2010

distances and host galaxies

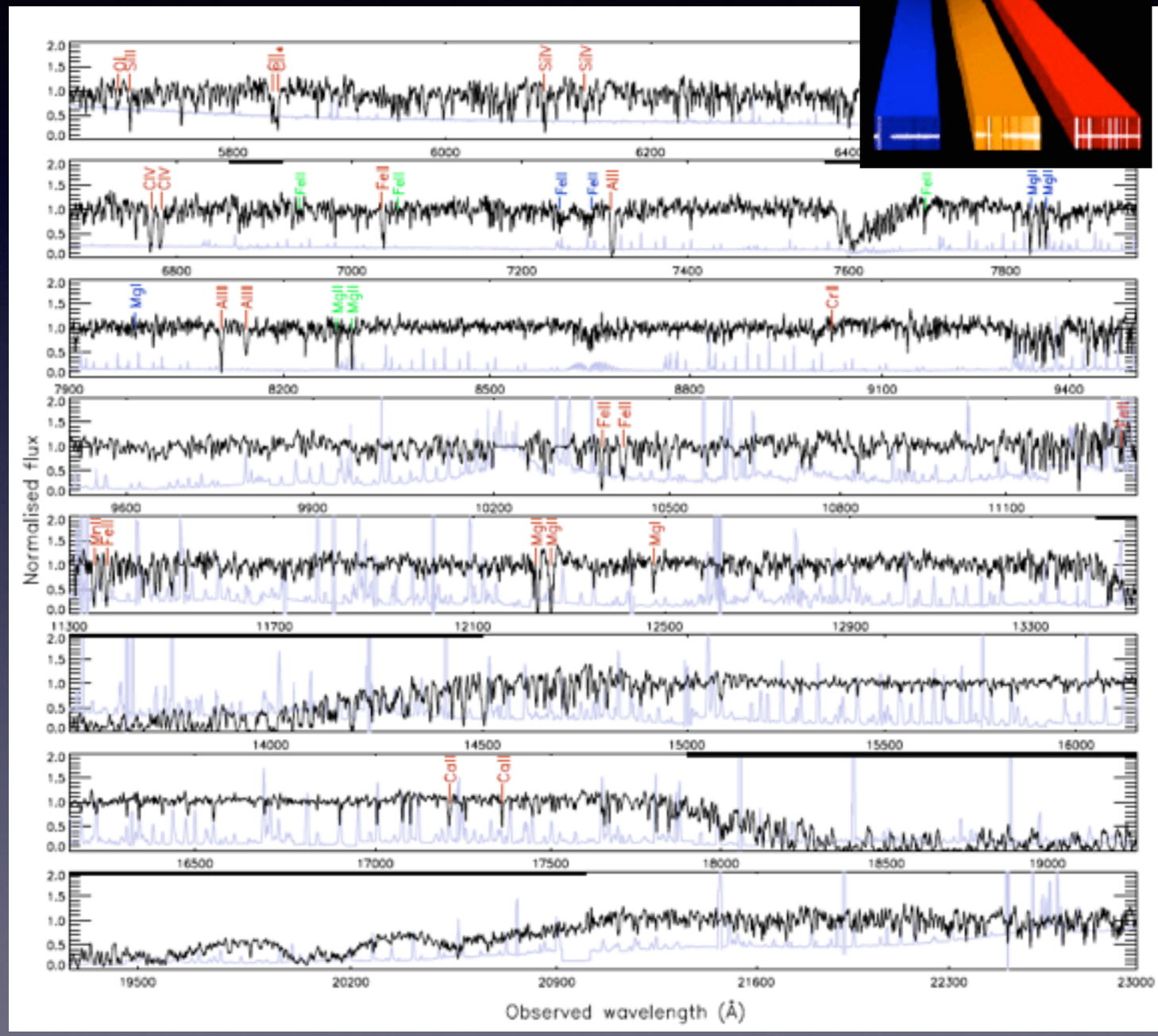


NASA & Fruchter

spectroscopy

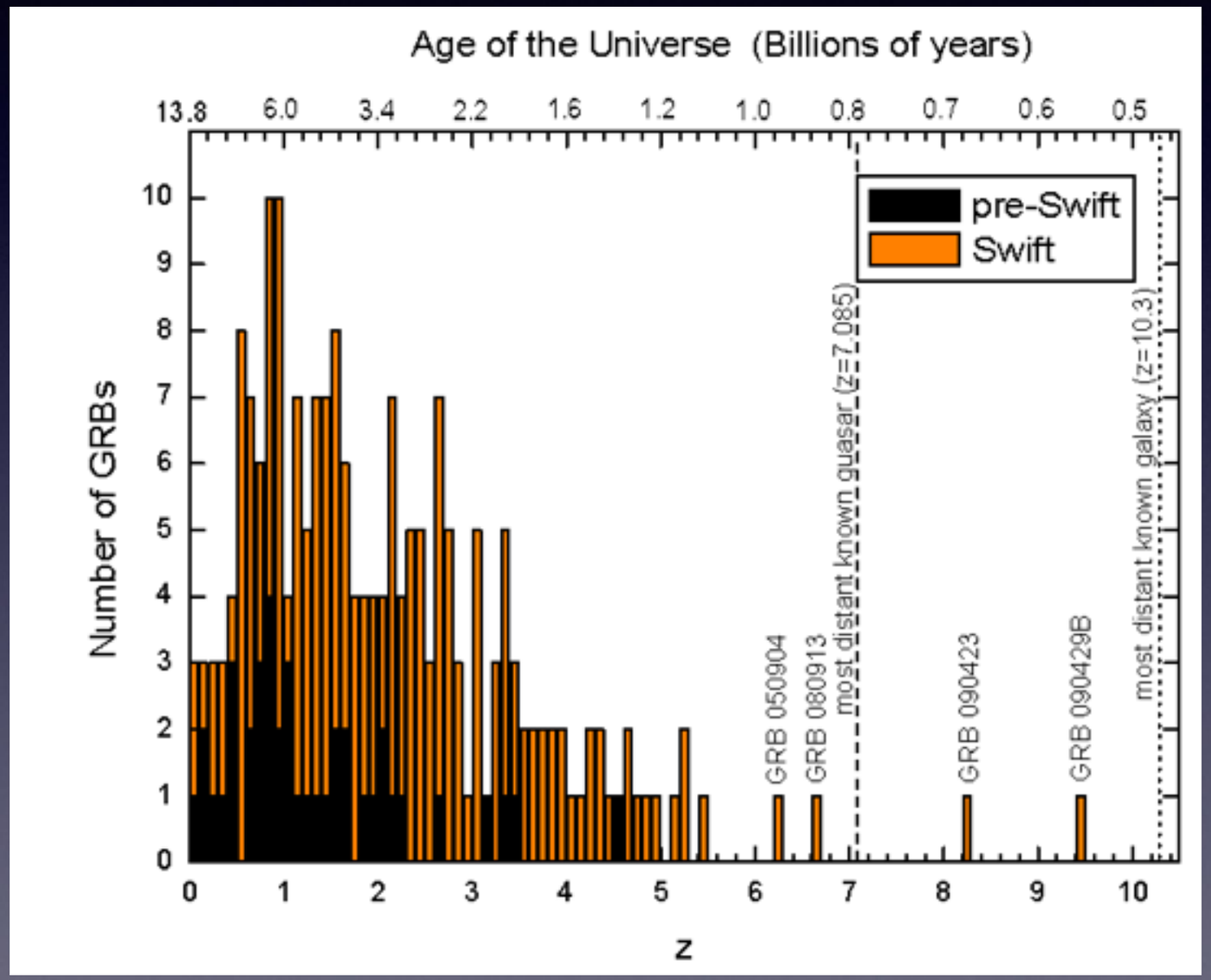
- big telescopes
- X-shooter at Very Large Telescope
- optical afterglows and/or host galaxies reveal:

  cosmological redshift
  ⇒ distance



de Ugarte Postigo 2010

redshift distribution

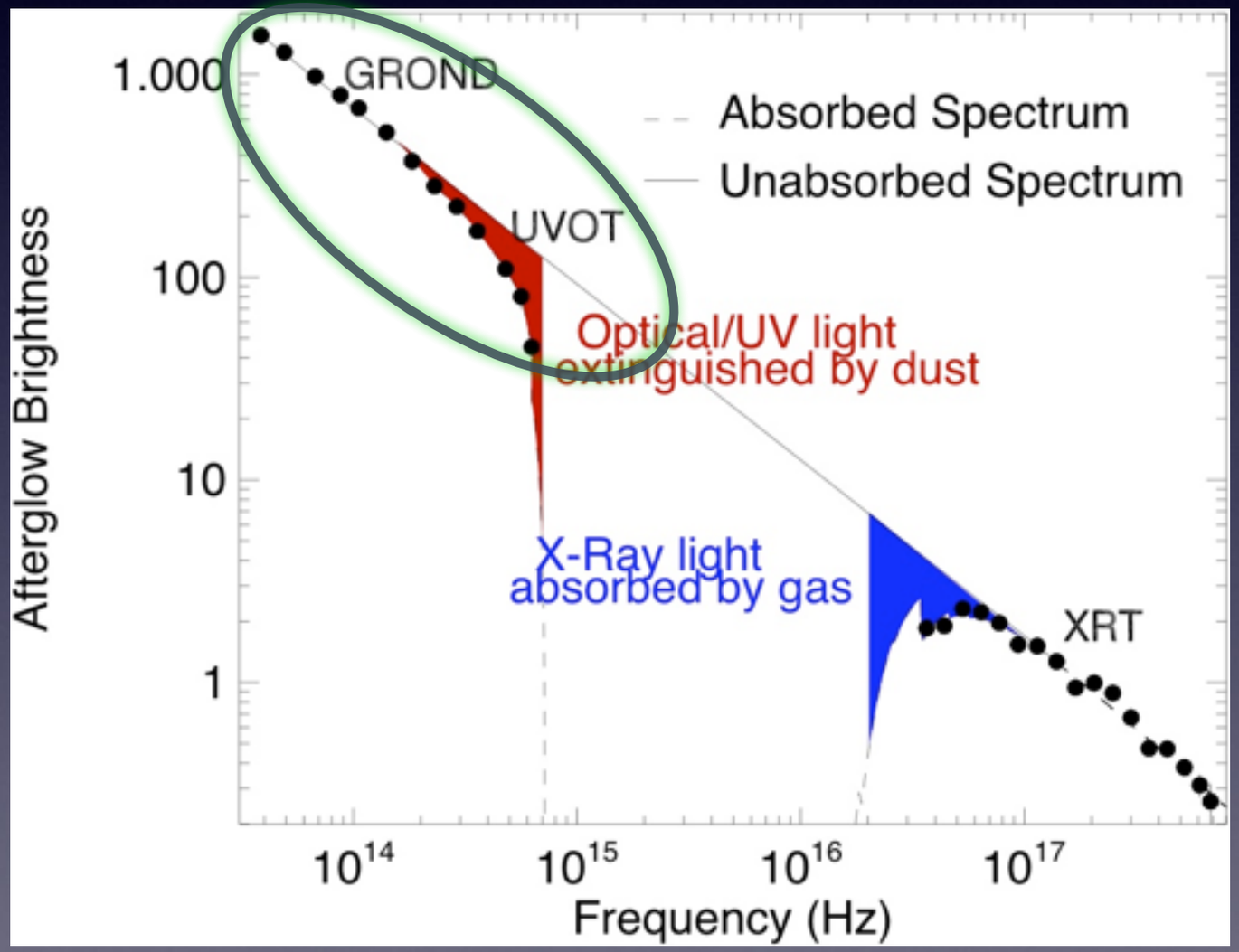


$E_{beam.\ corr.} \sim 10^{40}\text{-}10^{46}$ J

Gomboc 2012

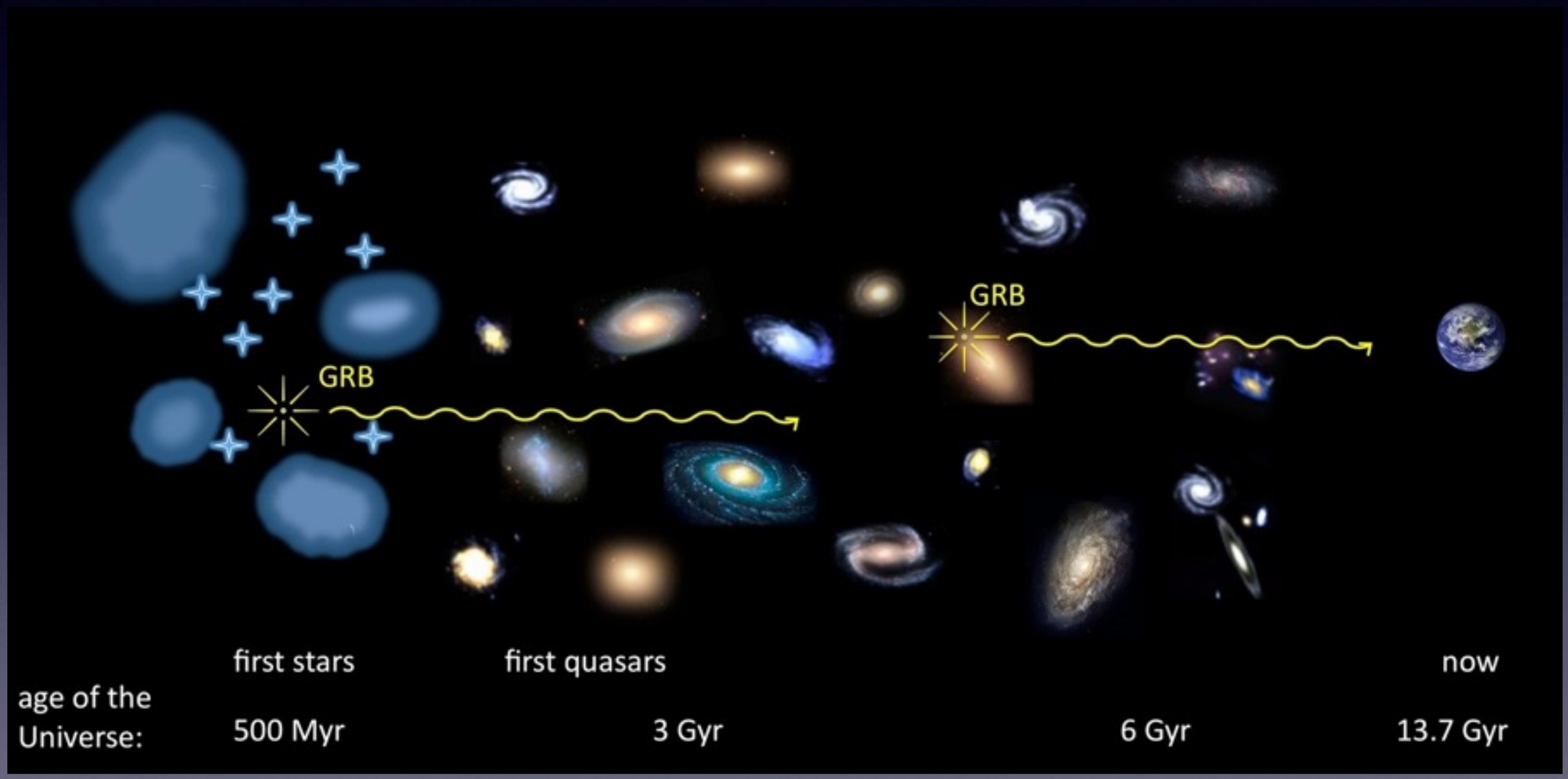
SED and spectra

reveal radiation mechanism and material in the line of sight:



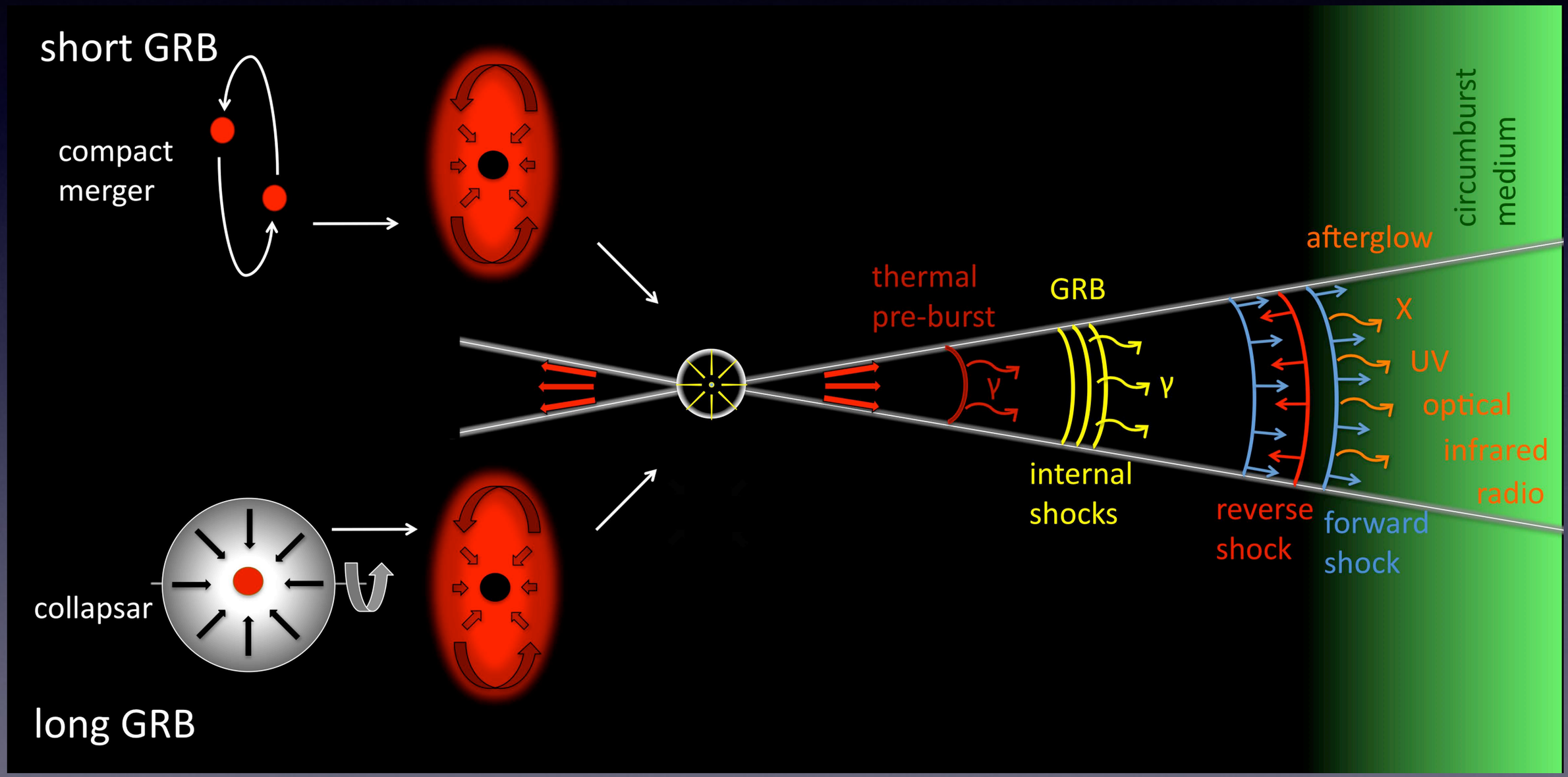
Shady

cosmological probes



Gomboc 2012

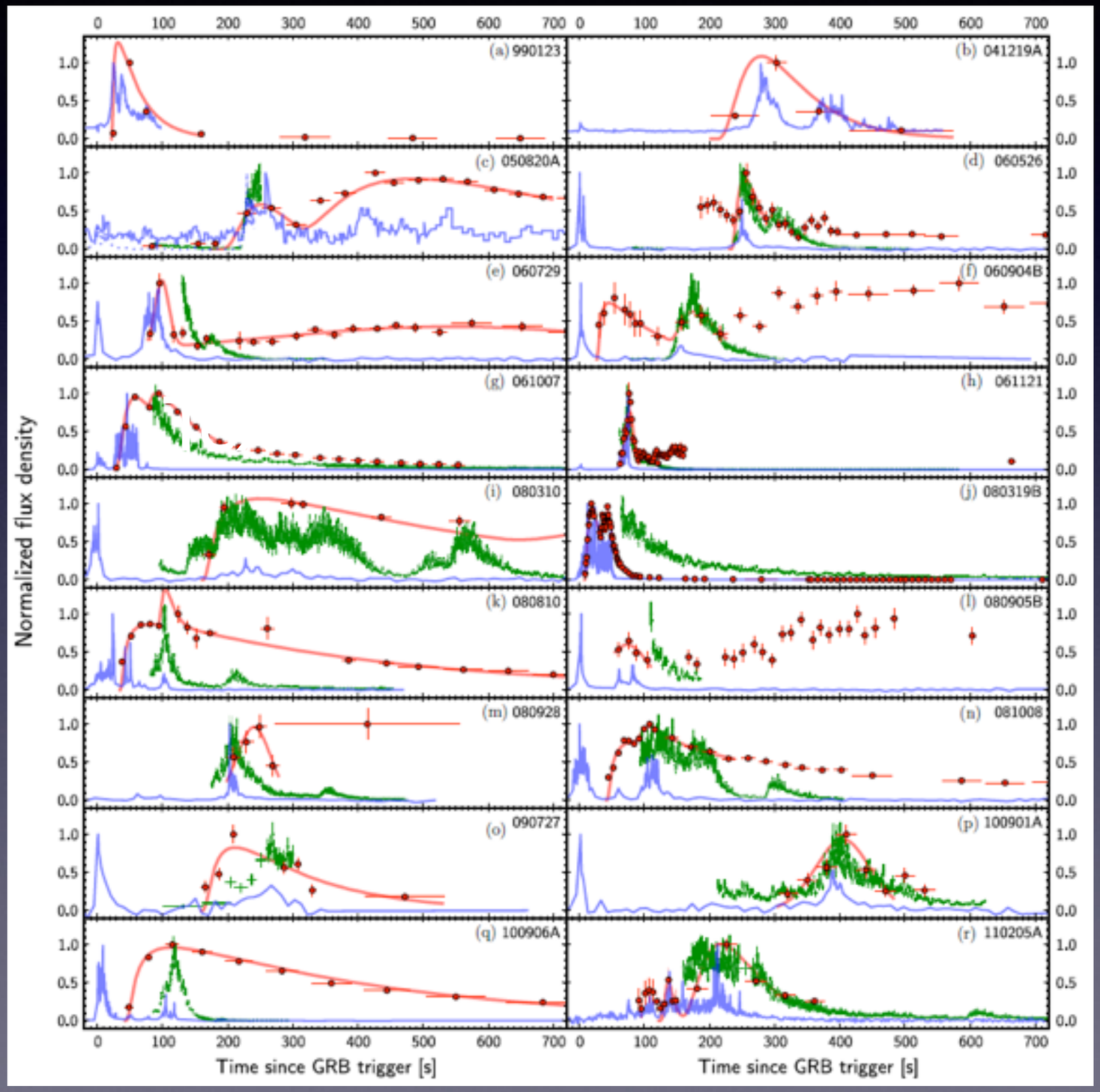
fireball model



Gomboc 2012

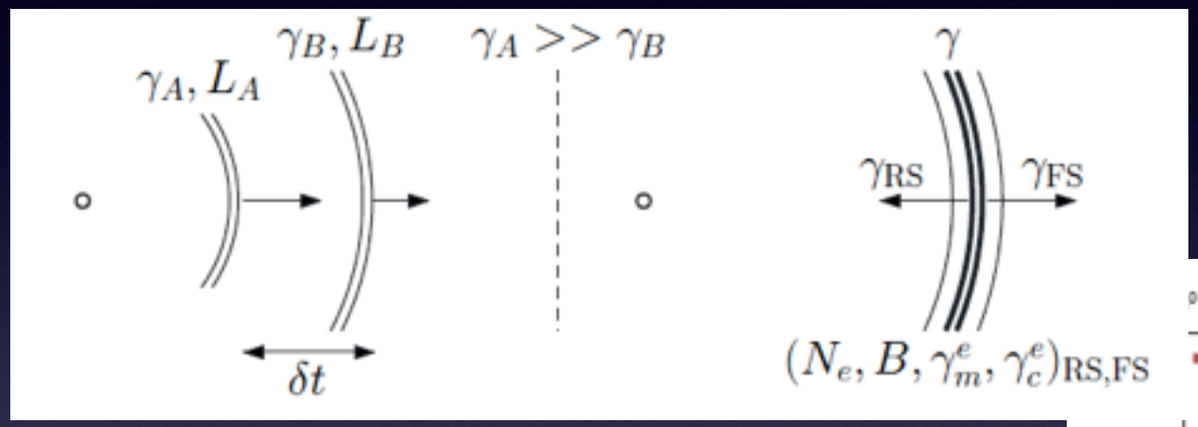
I. early optical emission

- GRBs with early observations
- showing optical peaks
- prompt emission or beginning of afterglow?

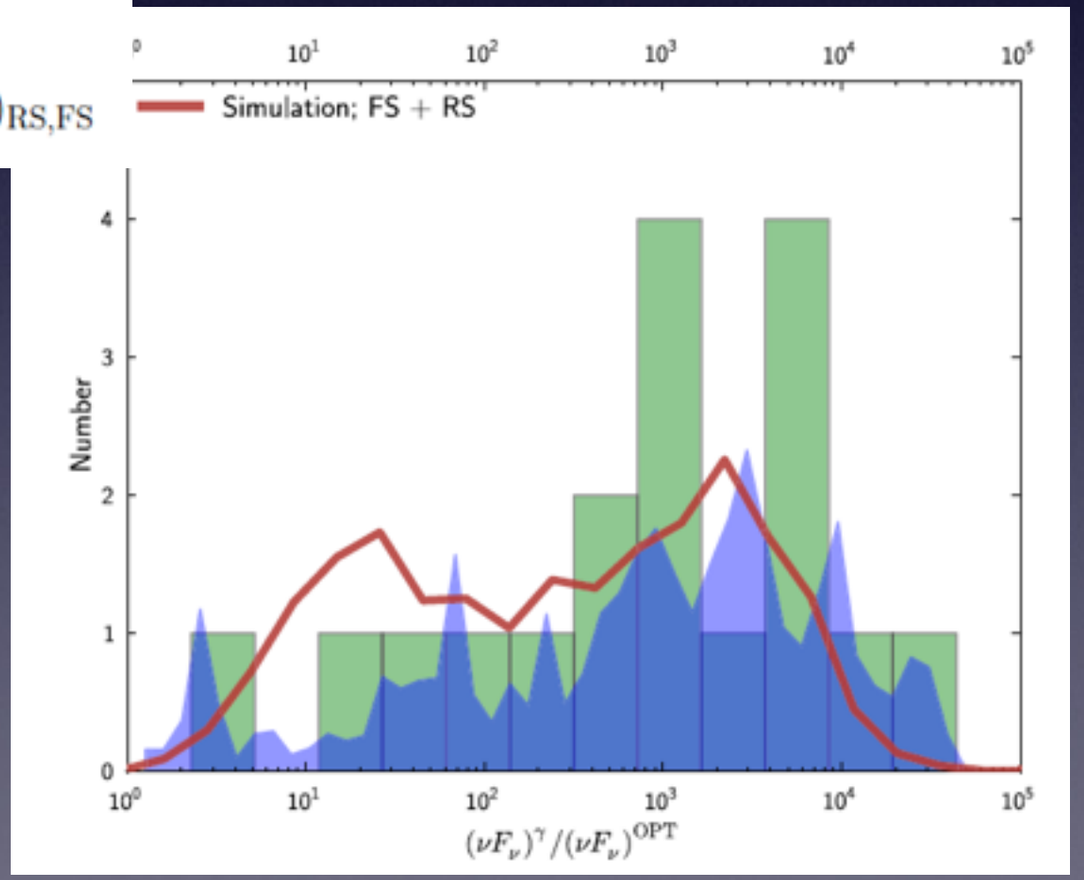


Kopač et al. 2013

model - collisions of shells



- comparing flux ratios
- consistent with internal shock scenario - prompt!

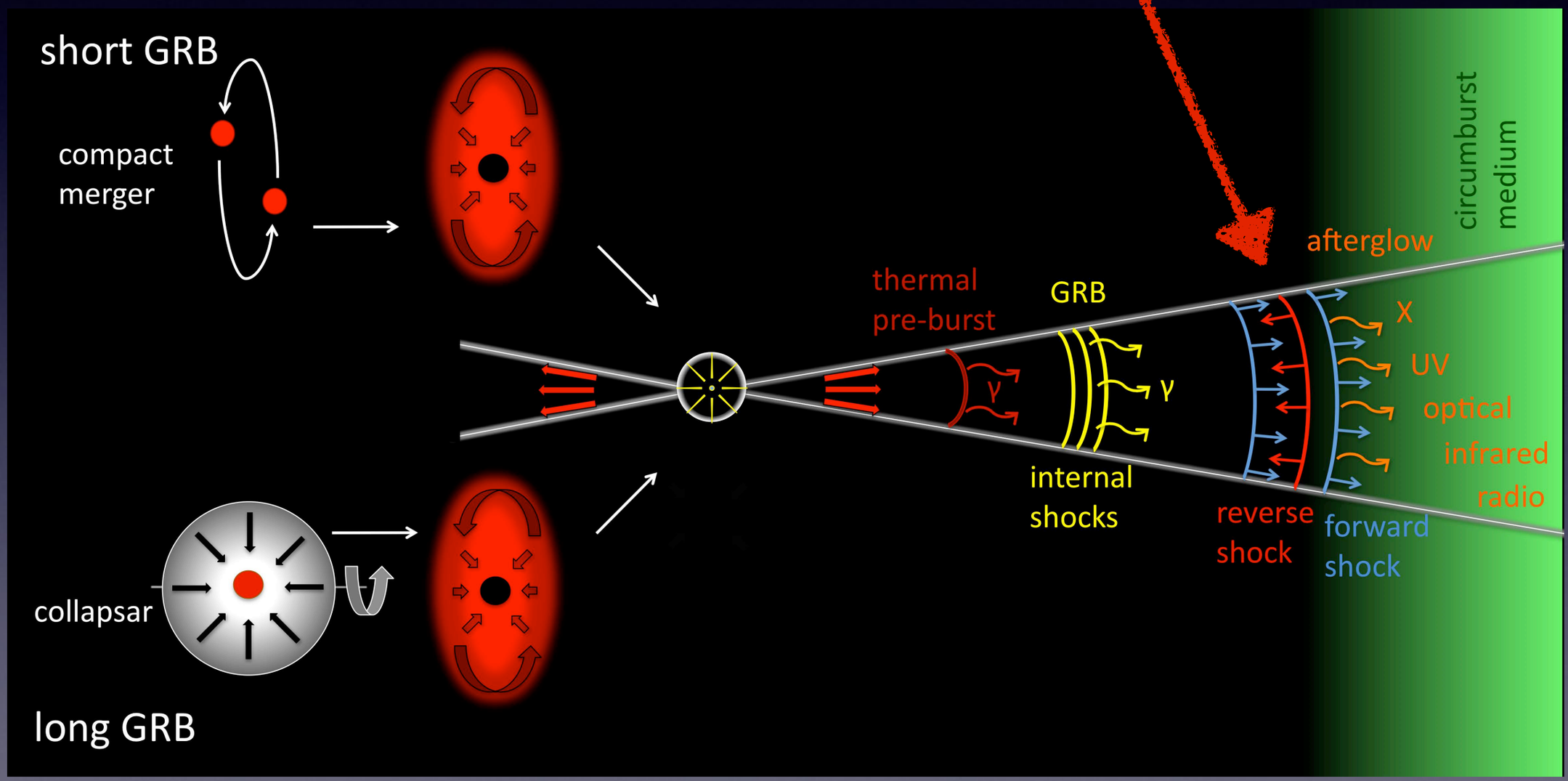


Kopač et al. 2013

2. magnetic field

- driving the outflow?
- random (local) or ordered (global, originating from central engine)?

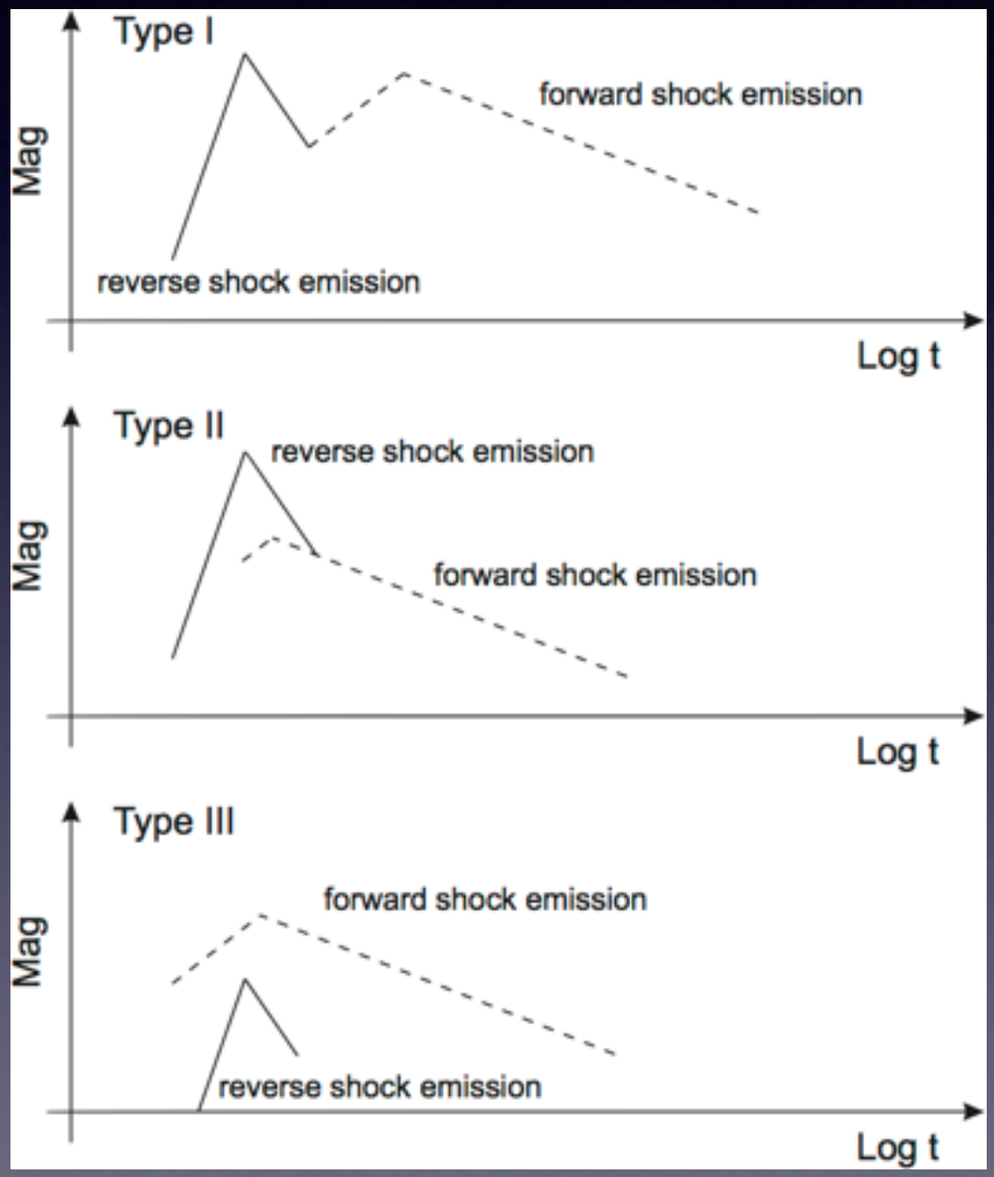
reverse shock



Gomboc 2012

reverse shock sample study

- whole sample:
  118 GRBs
- reverse shock signature:
  10 GRBs
- corrected for Galactic and host galaxy extinction
- shifted to GRB rest frame (standard cosmology: $H_0=71 kms^{-1}Mpc^{-1}$, $\Omega_M=0.3$, $\Omega_L=0.7$)

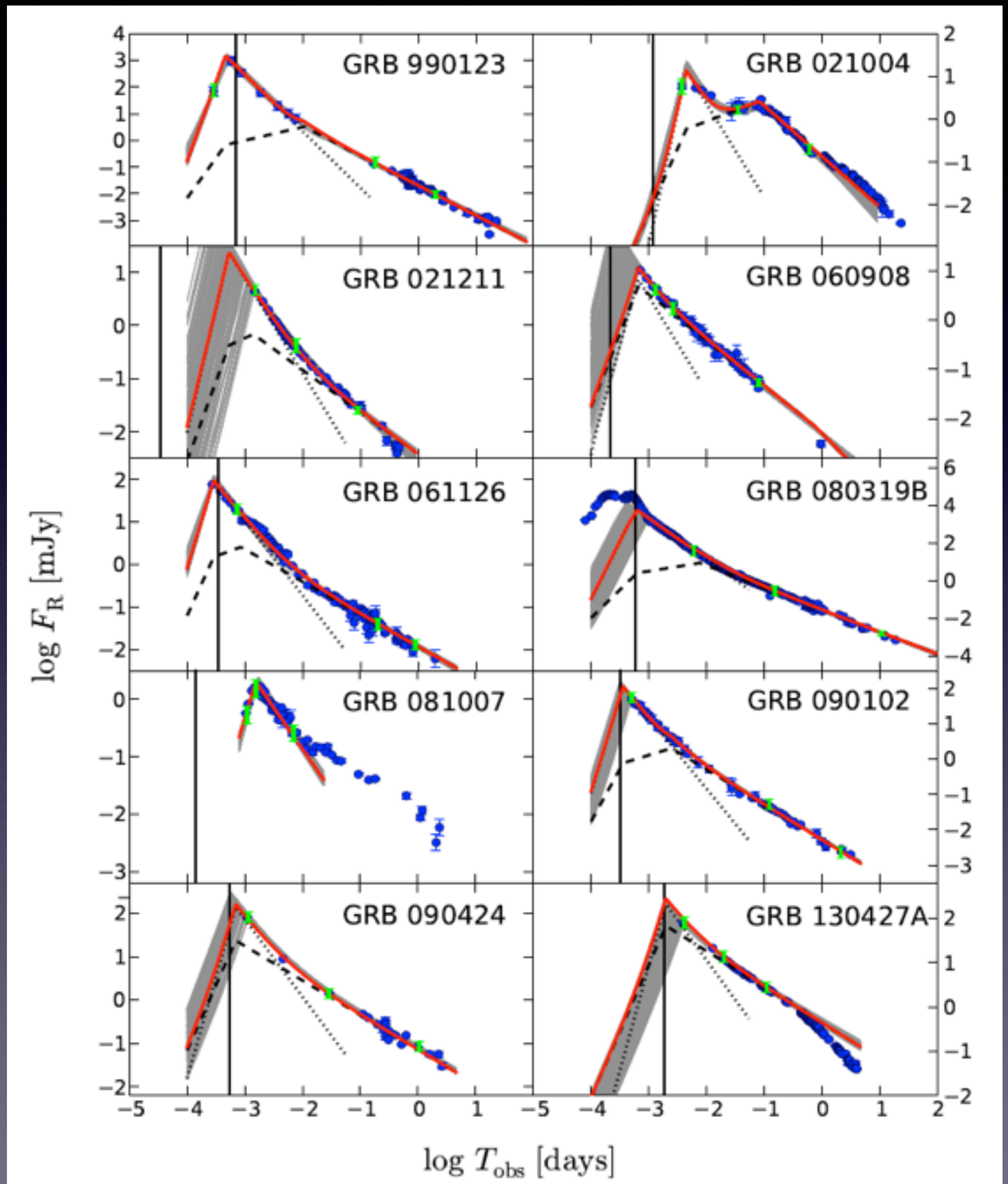


Gomboc et al. 2009

model: forward+reverse

parameter space:

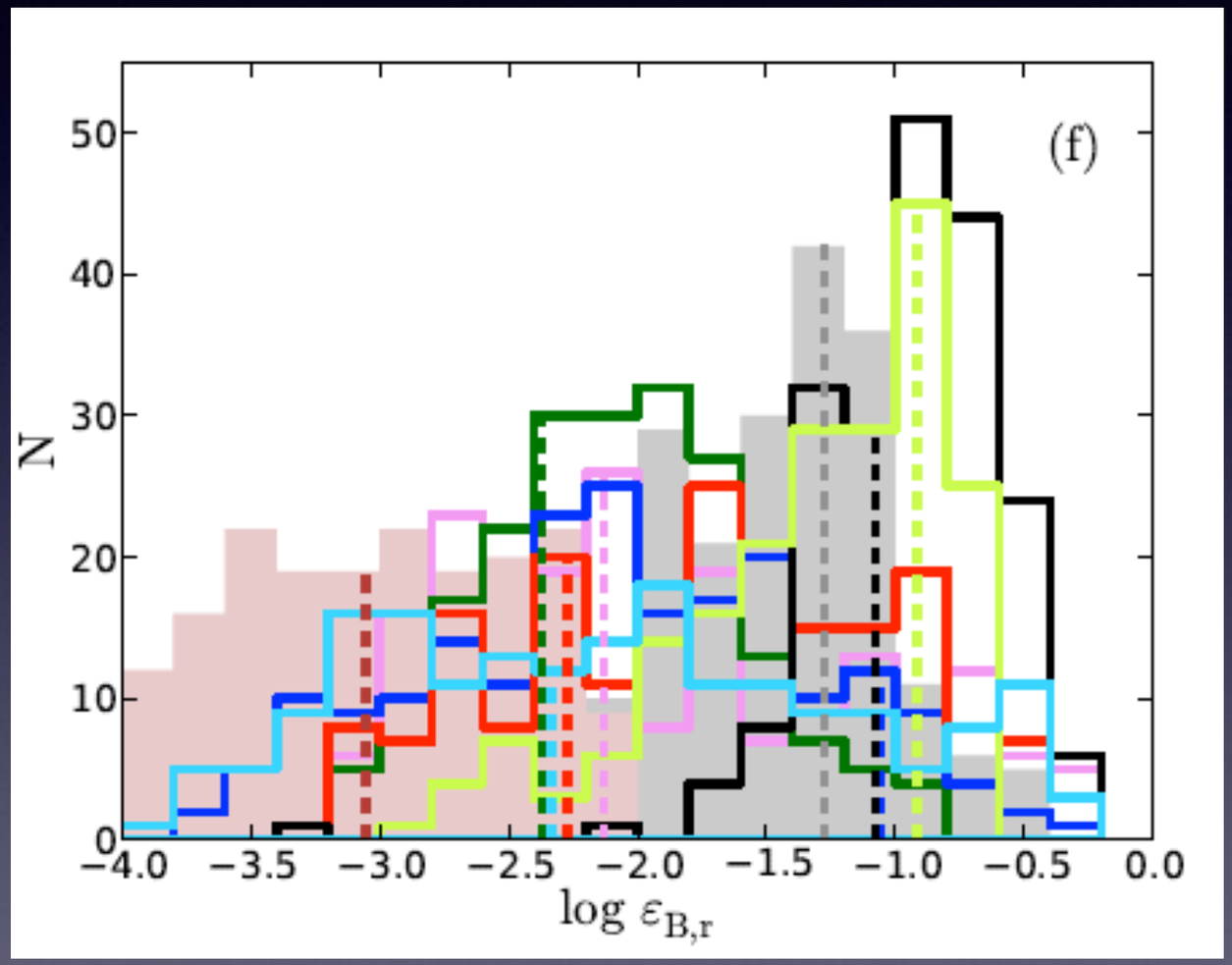
- p...electron distribution index
- n...density of circum burst ISM
- γ_0...initial Lorentz factor of the shell
- E_K...isotropic equivalent kinetic energy of the shell
- ε_e ...ratio of electron energy density and internal energy density
- $\varepsilon_{B,r}$, $\varepsilon_{B,f}$ ... ratio of magnetic energy density to internal energy density
- $R_B=\varepsilon_{B,r}/\varepsilon_{B,f}$



Japelj et al. 2014

ratio of magnetic to internal energy in the reverse shock:

< 1: magnetic field is not dominating the fireball evolution

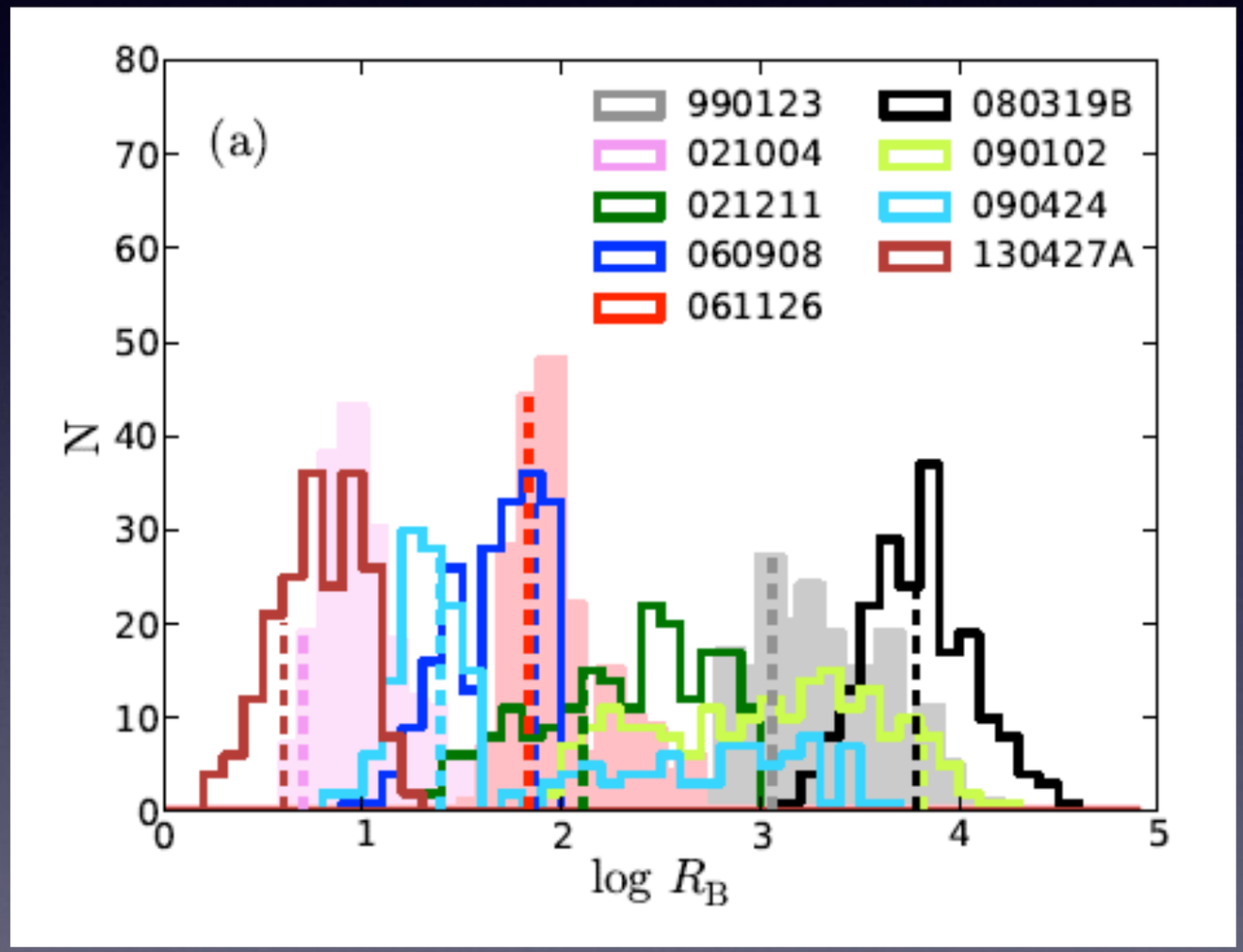


Japelj et al. 2014

magnetization parameter:

$R_B = \varepsilon_{B,r} / \varepsilon_{B,f}$

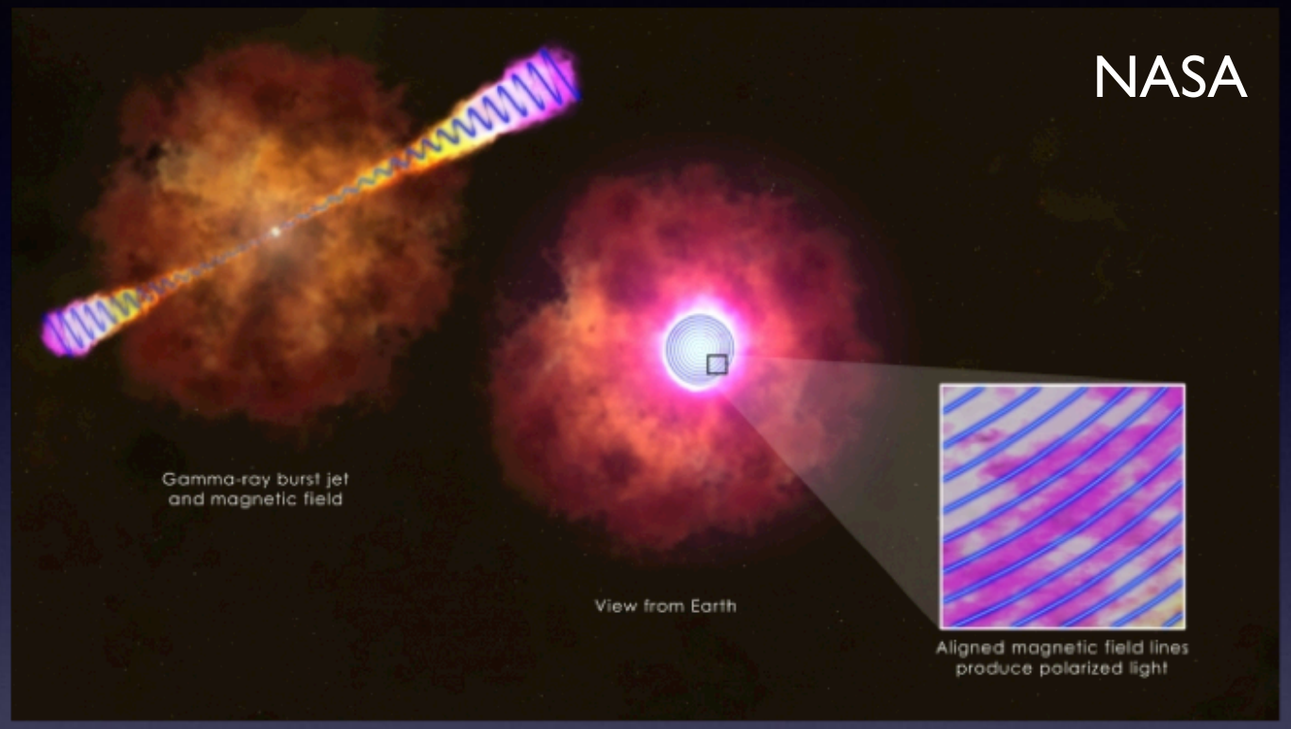
$R_B = 2 - 10^4$



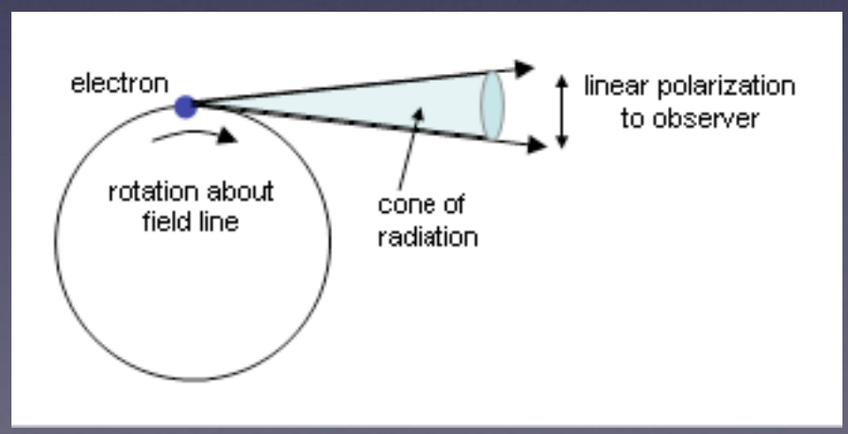
Japelj et al. 2014

polarisation

- compression of magnetic field in the shock plane - B ⊥ to line of sight



- an electron moves around the magnetic field lines and radiates in angle: $1/\gamma_e$
- view in the plane of motion ⟶ linear polarisation



linear polarisation

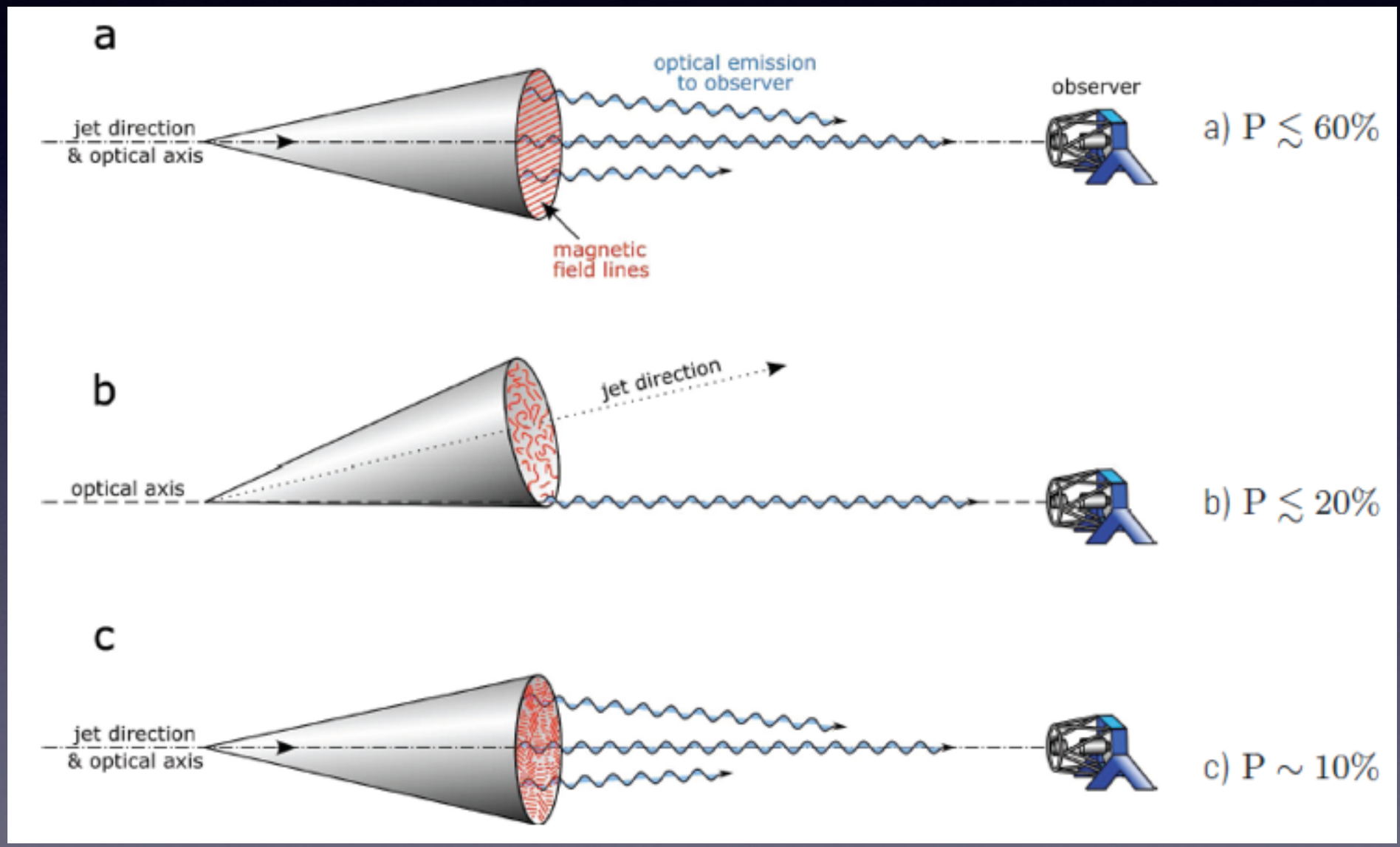
- macroscopically: collimated beam of mono-energetic e^- $\longrightarrow$ synchrotron radiation linearly polarised $\perp$ to projected B and line of sight
- power-law distribution of e^- energies:

$$N(\gamma_e)d\gamma_e \propto \gamma_e^{-p} d\gamma_e, \gamma_e \geq \gamma_m$$

- gives: P= (p+1)/(p+7/3) = 70%

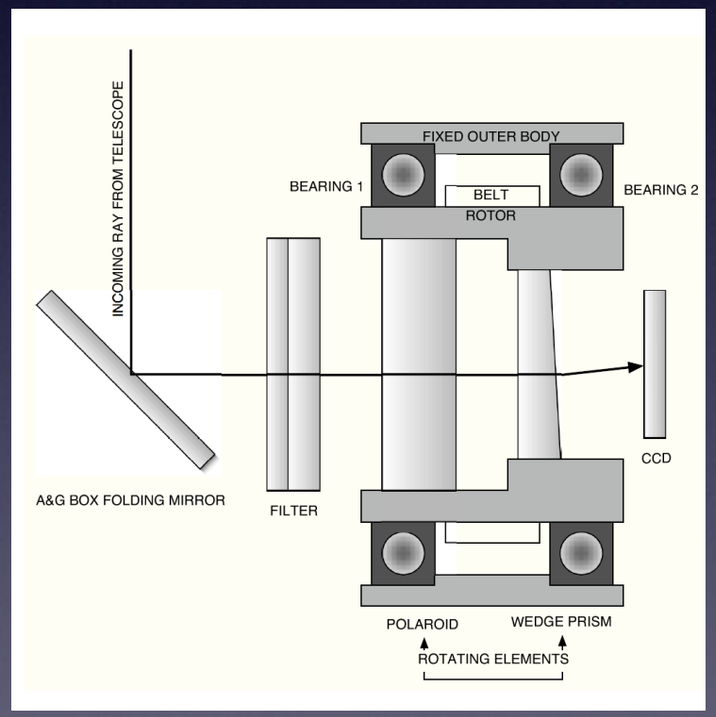
  (for p≈2, isotropic e^- distribution, perfectly ordered magnetic field, optically thin plasma) (Trippe 2014)

linear polarisation of optical afterglow



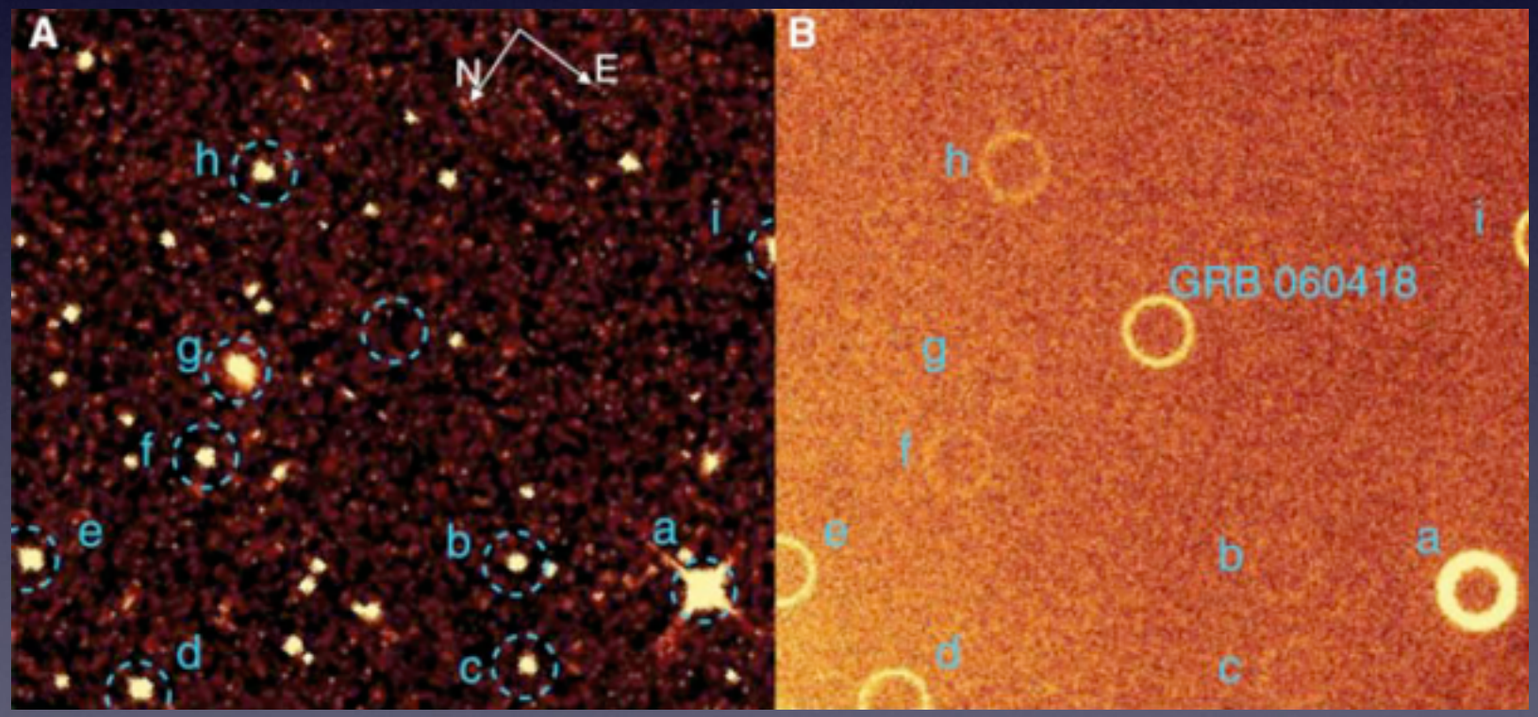
Steele et al., 2009

RINGO polarimeter @ LT



Steele et al., 2006

GRB 060418

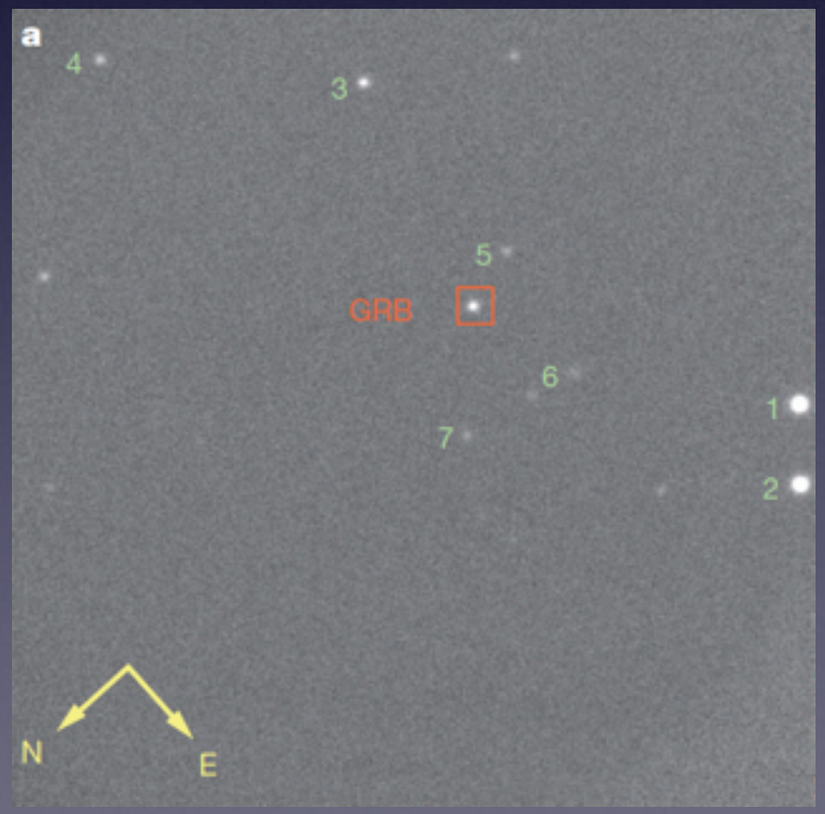


Mundell et al. 2007

upper limit P<8% (P=3.8%)

GRB 120308A

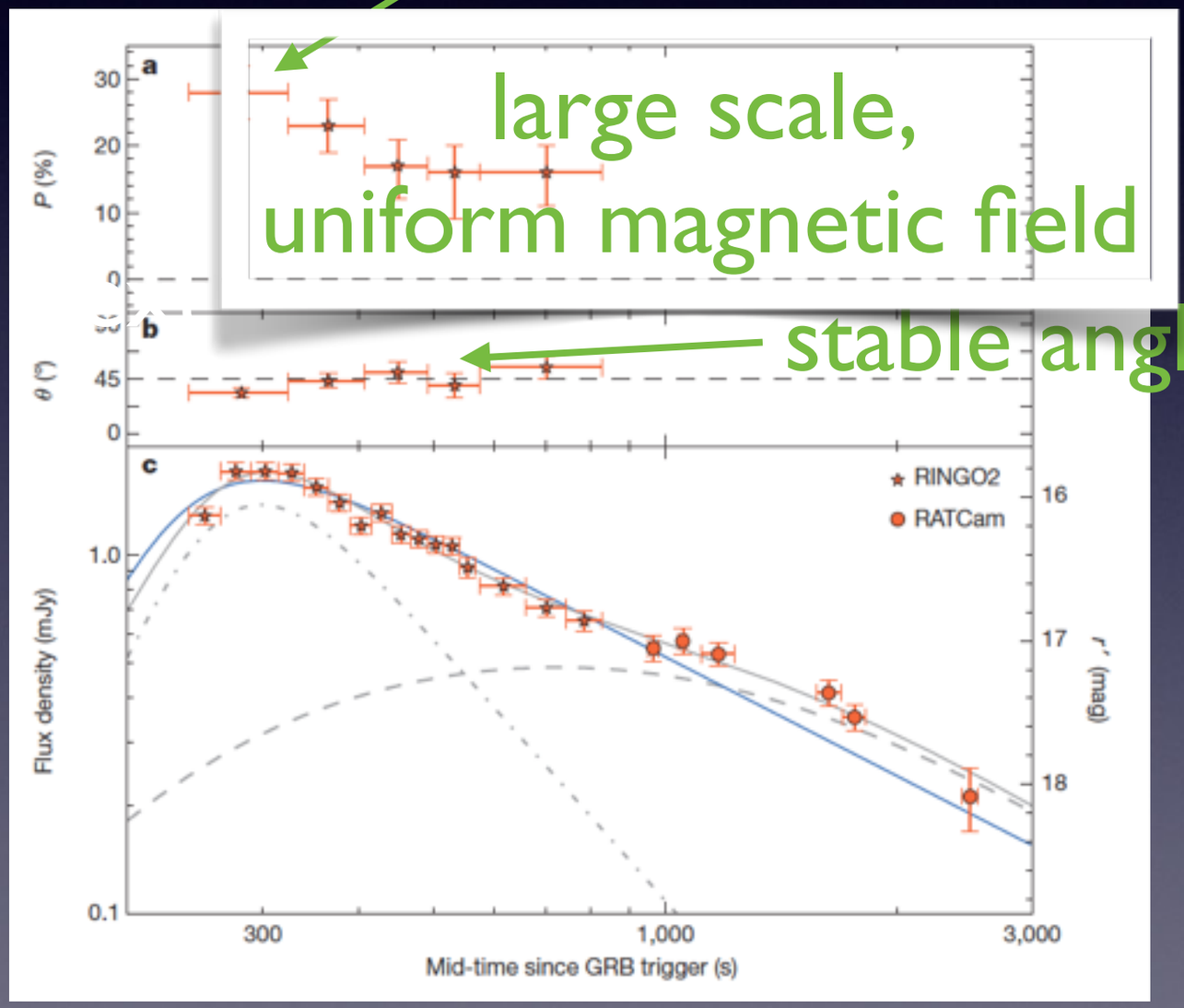
RINGO 2 frame



high polarisation

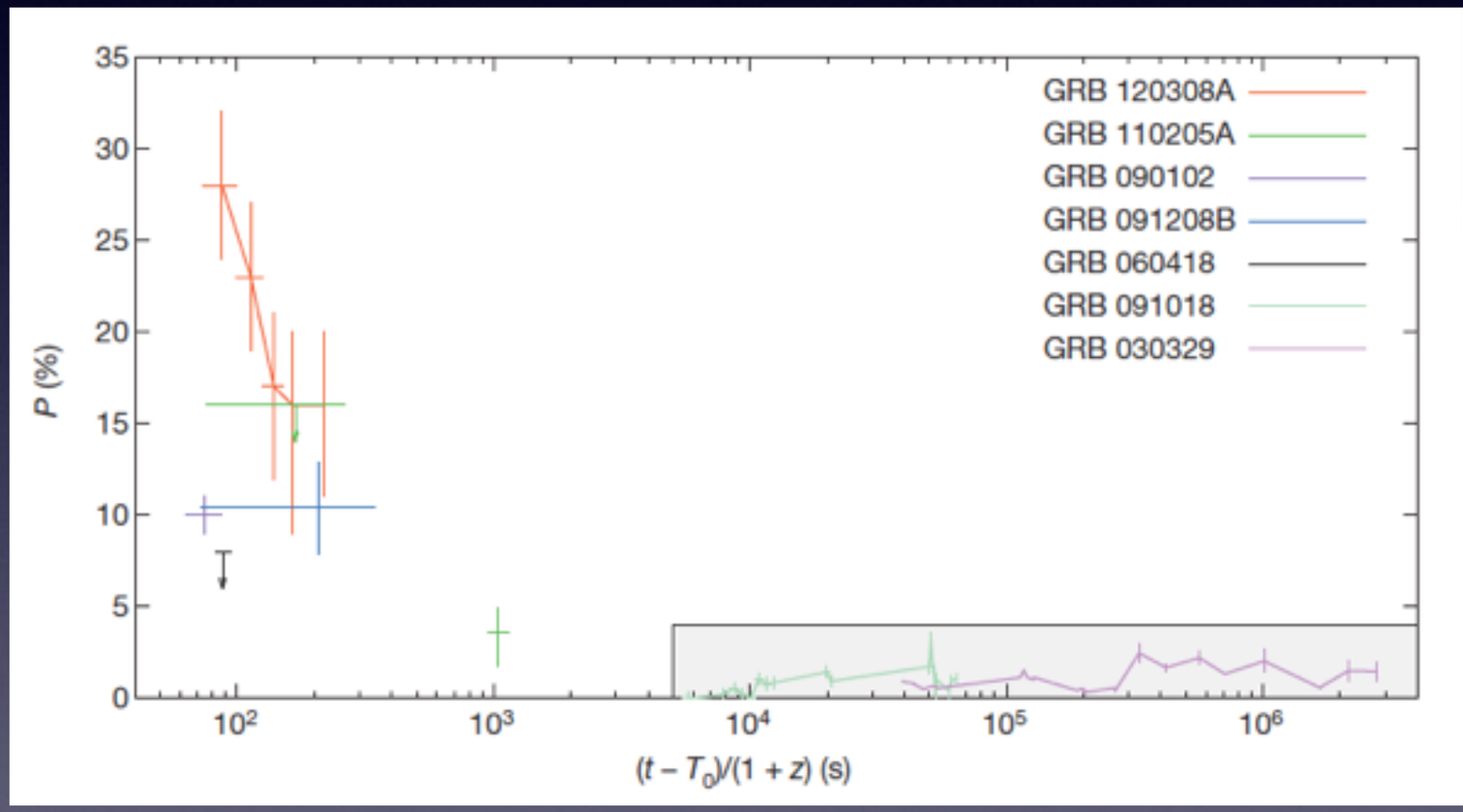
large scale,
uniform magnetic field

stable angle



Mundell et al. 2013

first measurement of early linear polarisation temporal evolution



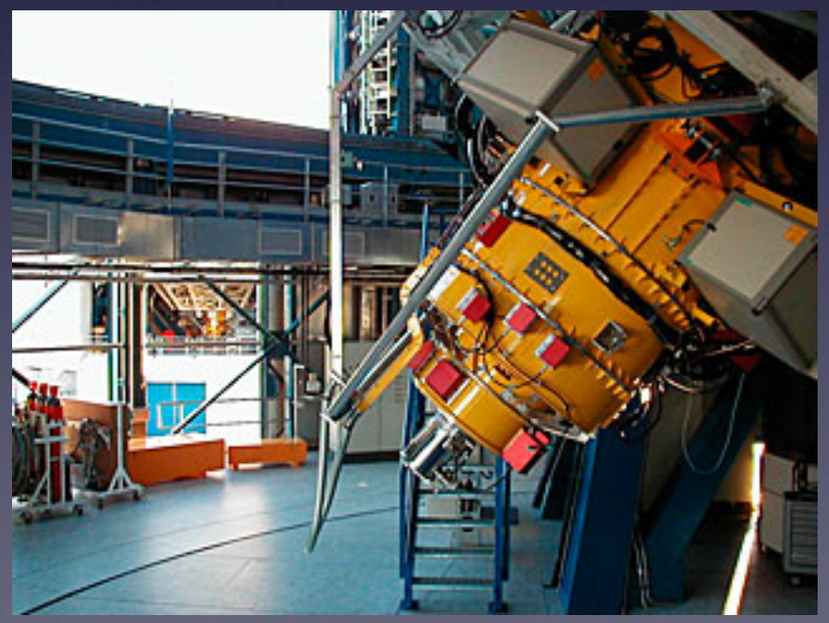
Mundell et al. 2013

circular polarisation

- theoretical prediction by Matsumiya&Ioka 2003:
- tangled magnetic field: no circular polarisation
- ordered magnetic field: $P_{circ} \sim 1/\gamma_e$

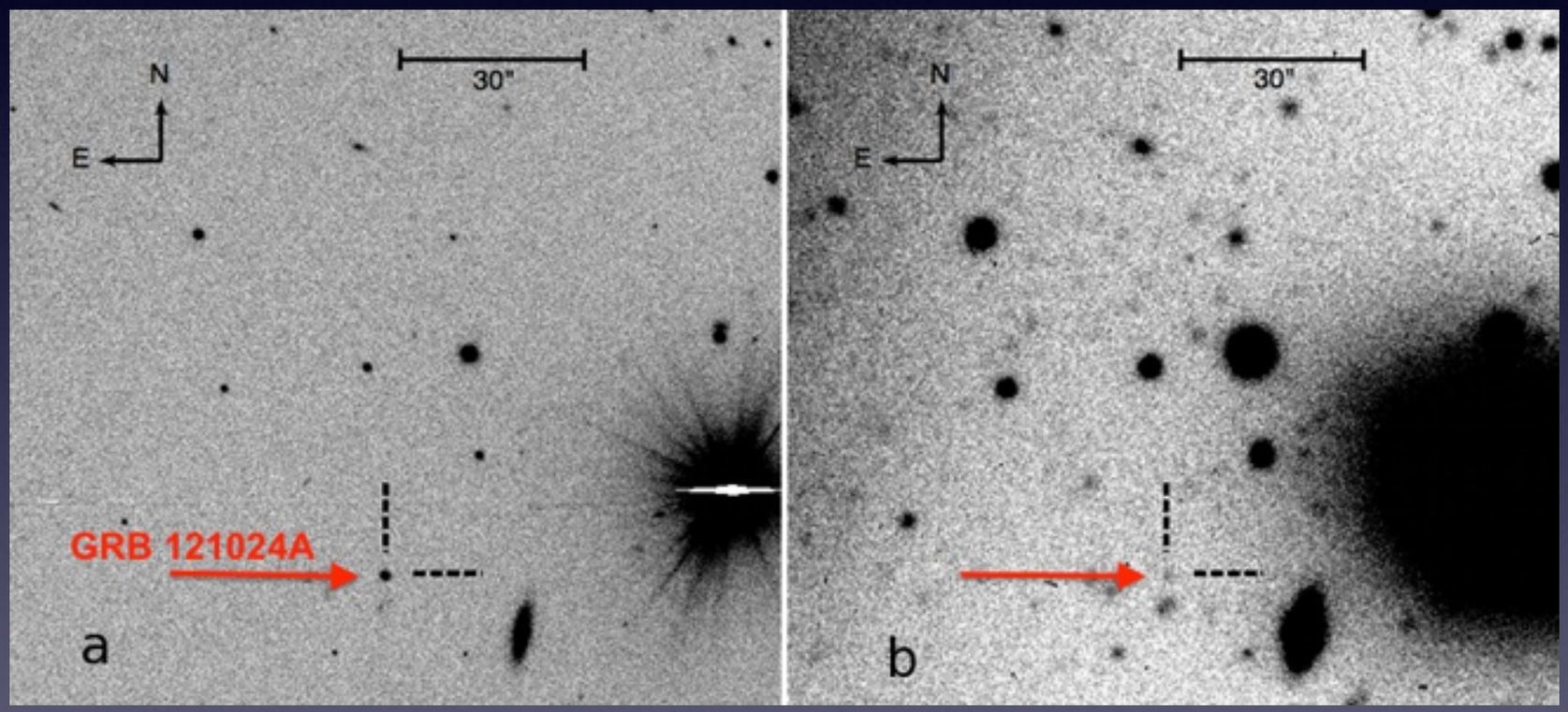
  P_{circ} ~0.01% (forward shock)

  P_{circ} ~0.01-0.1% (reverse shock)
- FORS 2 @ VLT



ESO

GRB 121024A

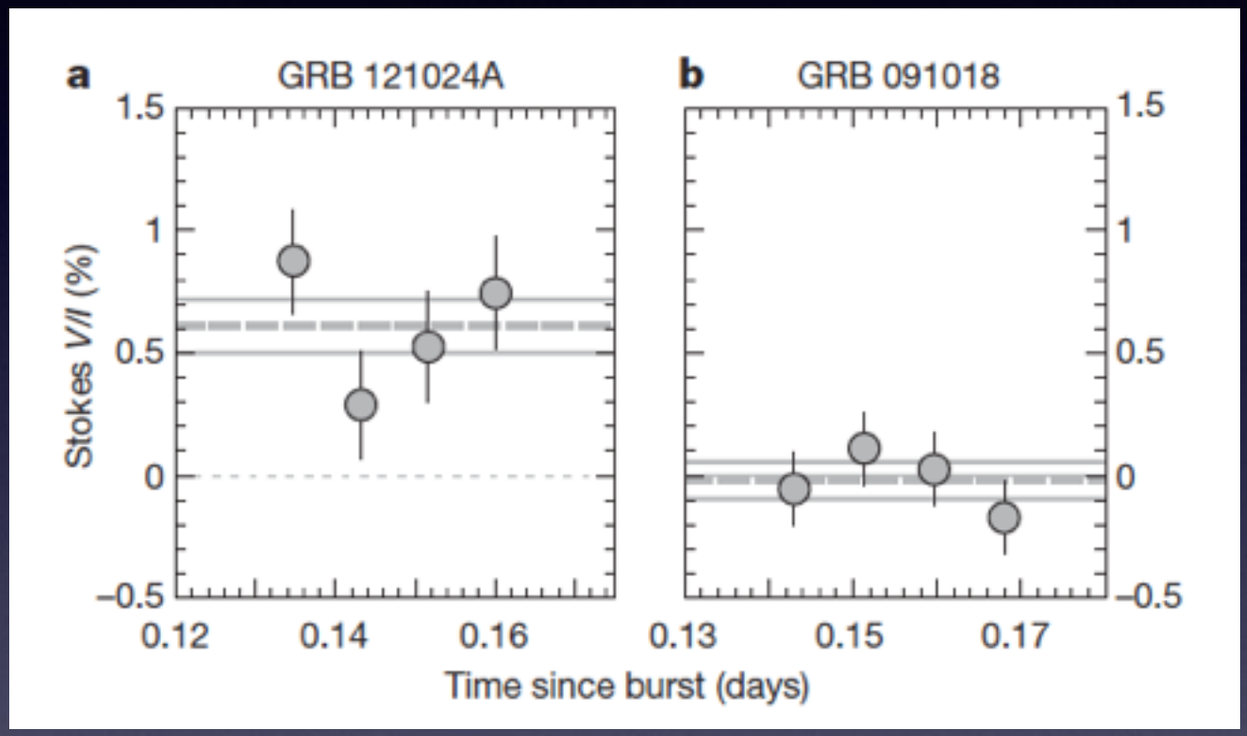


circular polarisation

$P_{lin} \approx 4\%$

$P_{circ} = 0.61\% \pm 0.13\%$

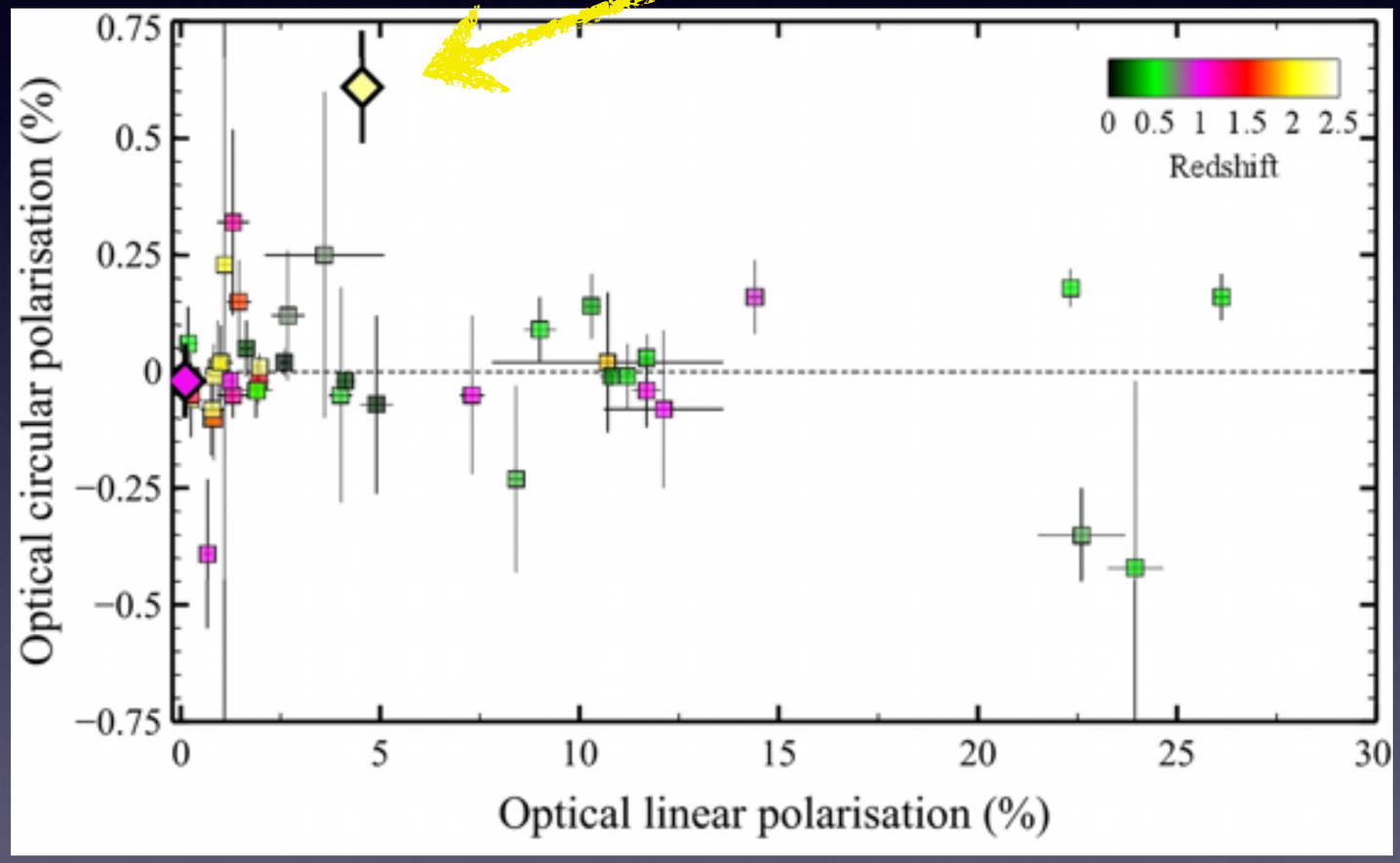
$P_{circ}/P_{lin} \approx 0.15 > \sim 10^{-4}$



Wiersema et al. 2014

not due to dust scattering or plasma propagation effects ⇒ intrinsic

GRB 121024A



Wiersema et al. 2014

Conclusions

- many open questions
- optical observations complement X- and gamma-ray observations

Thank you!

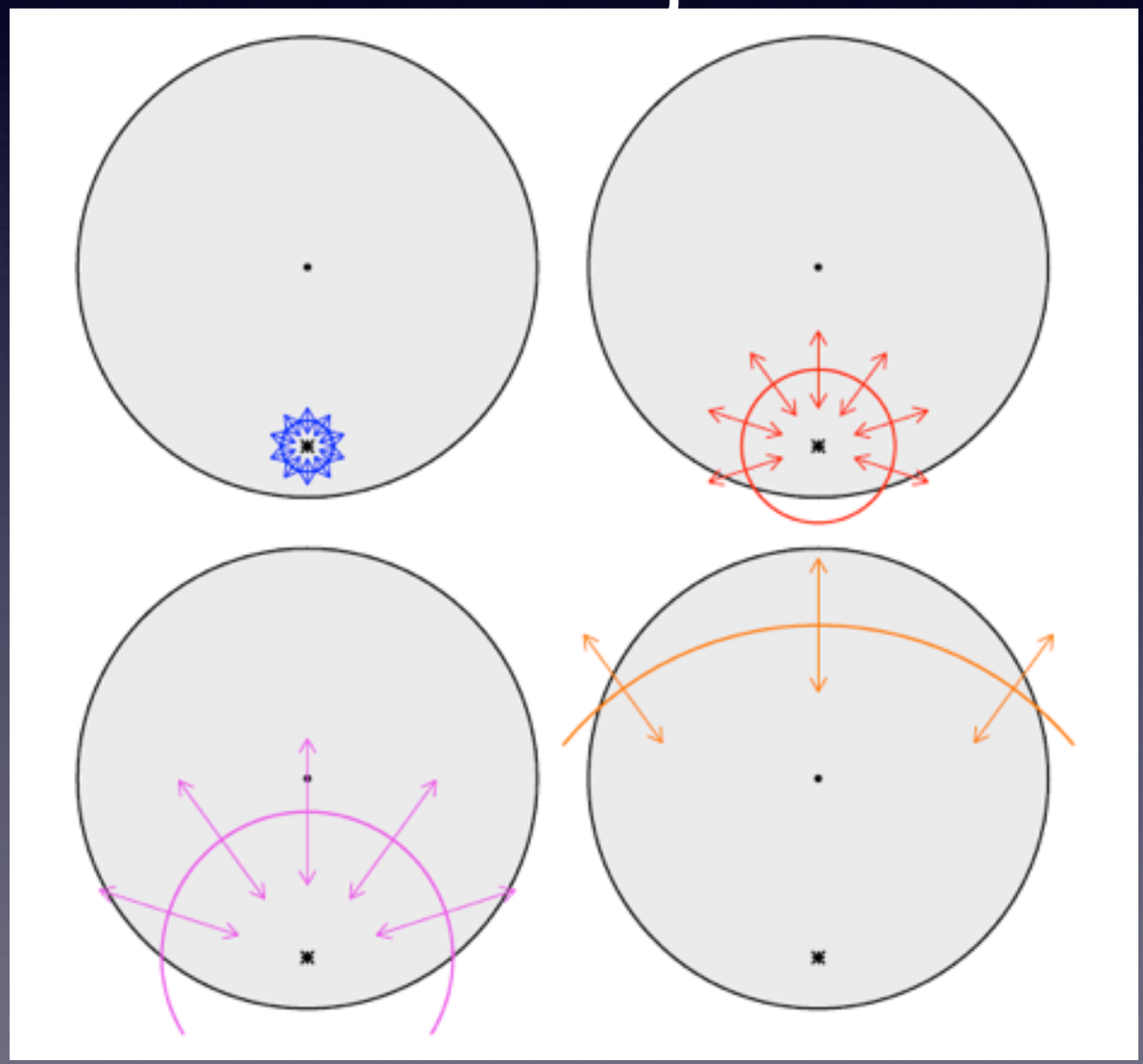
large scale, ordered magnetic field

- Granot & Königl 1999:
  - high degree of polarisation of early afterglow
  - reverse shock (more polarised) + forward shock component in light curve $\longrightarrow$ P<70% and variations with varying light-curve
  - constant position angle

tangled magnetic field

- an observer sees only radiation coming from a small circle
- in the observer frame, radiation is highly polarized in the local radial direction (Granot et al. 1999)
- observed out of symmetry axis ⟶ zero or low polarisation initially, increasing to 10-20%, going to 0 near the jet-break time, increasing again ⟶ 90° change in polarisation angle around time of jet-break, when the light curve becomes steeper

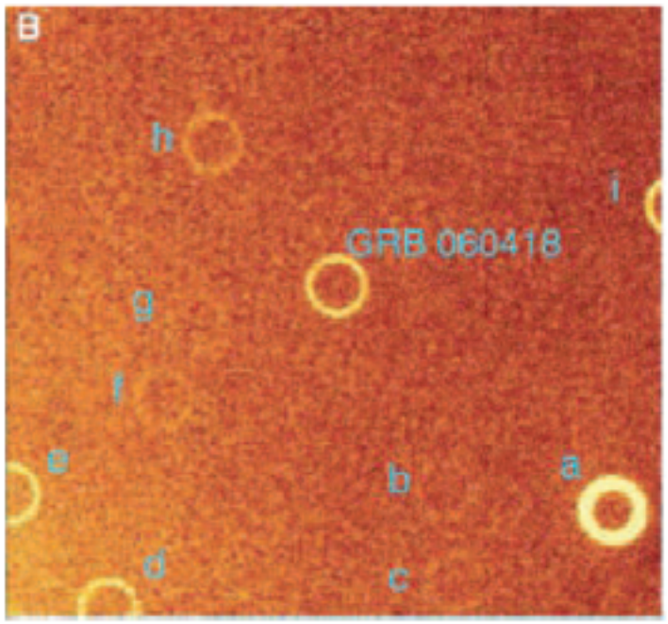
face-on jet

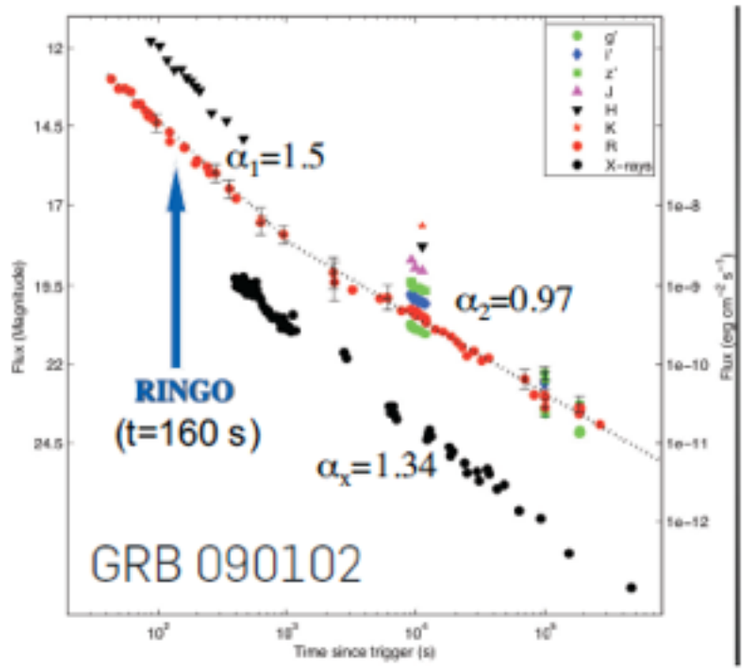


Lazzati, 2006

small patches of magnetic field

- Gruzinov & Waxman 1999:
  - if small patches of magnetic field, randomly oriented $\longrightarrow$ up to 10% net polarisation
  - erratic variations of position angle





$t - t_0 = 203\,\mathrm{s}$, $\mathrm{P} < 8\%$ (2σ):
hydrodynamic jet (Mundell et al. 2007)

$t - t_0 = 160\,\mathrm{s}$, $\mathrm{P} = 10\% \pm 1\%$:
magnetised jet (Steele et al. 2009)

	RINGO	RINGO2	RINGO3
Years of operation	2006 - 2009	2009 - 2012	2012 -
Temporal resolution	$\sim 10\,\mathrm{s}$	$\sim 1\,\mathrm{s}$	$\sim 1\,\mathrm{s}$
Wavelength Range at FWHM	$460 - 720\,\mathrm{nm}$	$460 - 720\,\mathrm{nm}$	$400 - 900\,\mathrm{nm}$
Polariser rotation speed	$500\,\mathrm{rpm}$	$60\,\mathrm{rpm}$	$60\,\mathrm{rpm}$
Camera	Apogee ALTA E42	Andor Xion+ 897	3 x Andor Xion+ 897
Operating temperature	$-10^\circ\,\mathrm{C}$	$-60^\circ\,\mathrm{C}$	$-60^\circ\,\mathrm{C}$
Readout time	$< 10\,\mathrm{s}$	negligible	negligible
Dark current	~ 1 electron/pixel/second	negligible	negligible
Filter	Hybrid ``V+R'' *	Hybrid ``V+R'' *	Two dichroic mirrors†
Sensitivity at $10\,\mathrm{s}$ exposure	$\Delta\mathrm{P} \sim 2\%$ accuracy $(R = 15\,\mathrm{mag})$	$\Delta\mathrm{P} \sim 0.7\%$ accuracy $(R = 15\,\mathrm{mag})$	
	$\Delta\mathrm{P} \sim 15\%$ accuracy $(R = 17\,\mathrm{mag})$	$\Delta\mathrm{P} \sim 2\%$ accuracy $(R = 17\,\mathrm{mag})$	

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